SPECIAL PROBLEMS ENCOUNTERED IN MODULAR DESIGN OF ELECTRONIC EQUIPMENT

BERNICE GLEN STAMPS

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by

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PREFACE

This paper was written to give the engineer who is not familiar with MODULAR CONSTRUCTION an idea of how this type equipment is designed, some of the problems encountered, and some of the new developments and changes that have occurred during the past year. A section is also included on component specifications to give an idea of the characteristics of the "tools" with which he has to work.

Most of the work was done and the data accumulated while on a ten weeks industrial tour which is part of the course of instruction at the U.S. Naval Postgraduate School. The industrial tour was made at Sanders Associates, Inc., located at Nashua, New Hampshire, from January to March 1954.

The author wishes to express his appreciation to Mr. Morton E. Goulder, Mr. Russ B. Hawes, Mr. John Peter Clark, Mr. H. W. Lalmond, and the other engineers and associates at Sanders Associates, Inc., whose advice and counsel helped immeasurably in the preparation of this paper.

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TABLE OF SYMBALS AND ABBREVIATIONS

coeff.	coefficient
$^{\circ}C$	temperature in degrees Centigrade
"	inches
I.F.	intermediate frequency
K	dielectric constant
L	length (centimeters)
mc.	megacycles per second
mfd.	capacity in microfarads
mmfd.	capacity in micromicrofarads
R.F.	radio frequency
temp.	temperature
VDC	direct current volts

CHAPTER I

INTRODUCTION

The TINKERTOY program is several years old now and is still progressing rapidly. The name, TINKERTOY, is no longer used; instead, when this type construction is used, it is referred to as MODULAR DESIGN or MODULAR CONSTRUCTION.

If the problem given had been to find a method of joining two pieces of metal together with machines, two methods of attack could possibly have been used. One would have been to design a machine to drill holes, put bolts and nuts in, and join the two pieces. A better method would have been to look for a process more amenable to machine production. This might have lead to spot welding the two pieces, which would have been much easier to do with machines. Similar reasoning was used in the development of the TINKERTOY type construction. The idea of taking conventional components and designing a machine to physically put them together was discarded. Though many new problems with components and design have arisen, these are offset by the flexibility and the ease of machine design that this system offers.

Whether or not the modulized design as it appears today will last with time remains to be seen, but with the extensive use of electronics some method of mechanized production must be developed. This project has proven the feasibility of one method, and if a better method is developed the experience gained here will still be valuable.

In order to prevent much duplication, it will be assumed that the reader of this paper has a knowledge of the basic principles of the system and has some knowledge of the components used. Necessary background may be obtained from Ref. 1 and Ref. 2 of the Bibliography. The progress

has been so rapid in this field that little time has been taken to write down the valuable, and sometimes hard-earned, knowledge that has been accumulated by the relatively few engineers that have been with this project from its beginning. Problems still exist, but the basic methods of layout and construction have become somewhat standardized.

With the release of this process to industry this year the use will probably spread, and new engineers will be given the job of designing for this type construction. This paper is written with these new engineers to the field in mind.

The actual design of a circuit from beginning to end will not be attempted, but instead, the places where modulized design differ from conventional design will be pointed out. This difference occurs primarily in the layout of the modules, so this part will be considered in more detail than the overall design problem. The overall design problem is considered first and restrictions peculiar to modular construction are analyzed. A general method of attack to the module design problem is given and then a sample module design with a step-by-step solution is presented. The following section contains a discussion of some specific difficulties that have occurred and the solutions used. Reference is made to circuits that have been constructed and a few design sheets are given to familarize the reader with some actual designs that have been used.

The components field for modular construction is new and since it is imperative that the designer be familiar with the components that he is to use and their characteristics, a section on this field is included. This study of components is written with the designer in mind and goes

into details of component development only to the extent that it affects the design of equipment.

CHAPTER II

MODULIZED CIRCUIT DESIGN

1. General Design Procedure

In general, it may be said that the basic circuit design for modular construction is the same as for the conventional type, but there are a few type circuits which are not readily adaptable to this type construction. Transformer type circuits cause some difficulty because transformers do not fit into modules and must be mounted externally with their leads entering the modules through the printed circuit on the baseplates. This requires more time in construction, more space, and required that riser wires be left free for the entry of the transformer leads. If possible, such circuits should be changed to the RC coupled type.

At the present time the capacity of condensers is limited to about 0.015 micro-farads and this may call for some circuits to be redesigned. Circuits which use feedback or other methods of reducing the bypass capacity should be used. Small size electrolytic capacitors can be mounted external to the module, but this, as with the use of transformers is not desirable. The number of leads between stages should be kept to a minimum when using printed circuits because of the difficulty of crossing leads. This is true of any type of printed circuit construction, and is not peculiar to the modular type.

The major problems occur, not in the circuit design, but in the physical layout of components. This is caused by the unique shape of the components and the method of attachment. Even the simple circuits must be laid out completely by the engineer and the placement of no parts can be left to the technician. It therefore becomes necessary for the

engineer not only to know how to design the circuit, but he must know much more about commercial design and manufacturing techniques than is normally required. In this, as with any design, certain tricks can be used to simplify the work and many small problems come up which were not anticipated.

An analysis has been made of the methods of design, and a suggested procedure that has proven very helpful to the author will be outlined. A new type design sheet is also given which has proven helpful in visualizing the circuit while laying out the modules. While these suggestions may not be followed to the letter, they may be helpful to one encountering this type of construction for the first time. Each designer will no doubt develop his own specific approach after he has had a little experience.

The circuit should first be studied for possible changes to eliminate transformers and large capacitors where possible. Where two or more stages have common high voltage dropping or decoupling resistors it is sometimes more convenient to use separate filters for each stage. By doing this, the number of interconnecting leads between stages will be decreased and the baseplate design becomes simpler and less crowded. The module design is also somewhat simplified. While studying the overall diagram, convenient places should be selected to break the circuit into modules. Good judgement exercised at this point in the design can save difficulty in the latter stages. Because there is relatively little shielding within the module, an effort should be made to include the plate circuit of one stage and the grid circuit of the following stage in the same module. A good place to separate the modules seems to be at the grid of the tube.

At least a sketch of the baseplates should be started at this time. Printed circuit baseplates are universally used with this type construction so the inability to cross leads must be considered. Crossovers are relatively easy to make within the module, so the module is usually designed last. The baseplate connections may sometimes have to be changed because of problems in the module design, but these changes can usually be held to the changing of a lead or two and not a complete redesign. It is common practice now to use a top and a bottom baseplate, to put the high voltage and filament supply on the bottom baseplate, and to leave the top plate for the input and output, and other interconnecting leads.

With the circuit cut into sections and the preliminary baseplate design made, the individual module circuits should be drawn up, each on a separate module design sheet, and the module design begun. If possible, the tube should be oriented on the top wafer with the index on the same side as the index of the wafer. This has become somewhat standardized and helps in the construction and testing of the module. The orientation of the module should next be considered. With most tubes this does not cause difficulty because the grid and the plate are on opposite sides of the tube for isolation. The module, therefore, is oriented so that the input lead on the printed circuit is short and the output is on the opposite side. The tube leads are shifted around on the wafer to make a suitable riser wire available for the input and output leads. The riser wires can now be labeled on the module design sheet and the component layout begun.

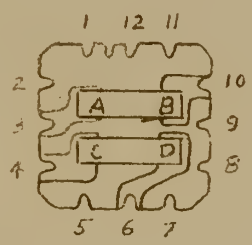
At this point consideration must be given to the number of parts and the most desirable location for them. It seems to be a good idea

to count up the number of resistors and the number of condensers to determine the minimum number of wafers that are needed. At the present time, because of production problems, a wafer is limited to either condensers or resistors, and not a combination of the two. If condensers and resistors were both used on the same wafer, it would have to be sent through both the resistor and condenser assembly lines, requiring twice the time to make. Up to four resistors can be used on one wafer, two on the top and two on the bottom. The number of condensers will be determined by the values to be used, because the value determines the size of each one. For small values under about 500 mmfd two can be used on each side without stacking provided the temperature coefficient is not critical. Where required, condensers can be stacked, but this requires that there be a common terminal between the two. Stacked condenser wafers are more difficult to construct so should not be used unless it is necessary. The resistors are more difficult to place because their leads are printed onto the wafers. This difficulty will be considered later.

By this time the number of wafers per module will have been determined, and since the module with the largest number of wafers will determine the minimum spacing of the baseplates, if one module is larger than the others, this part of the circuit can be examined to try and decrease the size of this module. There is no standard size for the modules, but designs have tended to use either a six- or nine-wafer module. If more than the minimum number of wafers is available for a module, the design usually is not difficult, but where most of the available wafer space is required for components, the design becomes more intricate and

tricks may have to be used in order to get all the parts in and connected correctly.

Before attempting a sample design it will be well to consider the problems encountered with the resistor wafers. These are straightforward and may seem trivial once they are seen, but almost every engineer on his first attempt will make mistakes with the resistor wafers. A full scale drawing of a wafer is shown, and from this, one can see the relative sizes of the wafer and the resistors. It is obvious that if two resistors are to be used on the same side of the wafer, they must be placed parallel to each other. The distance between the resistors and the notches on the sides of the wafer is small and the painted leads have a minimum width, so if short circuits are to be avoided in the manufacture of the wafer, the leads from the resistors can only be connected to certain notches.



Leads from the A end of the top resistor may go to riser notches 12, 1, or 3 without difficulty, but there is not enough space to run the A end to notch 4 or 11. The other ends have similar restrictions.

If the bottom resistor could better be used in the vertical position (if it connects to notches on the top and bottom side of the wafer) it may be possible to put it on the opposite side of the wafer and bring one of the resistors formally on the bottom and use it on the top in the

horizontal position. By appropriate juggling of the resistors, a solution may usually be found that is compatable with the construction. If no solution can be found, sometimes a spare riser wire is available so that the resistor can be brought out to this notch, follow up a spare wire and then be crossed over to the desired riser on another wafer. It can be seen now that resistor wafers, when using four resistors on them, are very poor as crossover points. Crossovers can usually be made between adjacent notches on resistor wafers because the painted leads do not extend very far in on the wafer. If the picture of the wafer and resistors is kept in mind while designing, the above problem can be minimized, but the design sheet can be misleading because of the ease with which the resistors can be drawn in and connected.

Before the sample design is begun, refer to Fig. 2, 3, 6 and 7. These show how designs are made in industry at this time. Pick a point in the circuit and try to find it in the layout of the module as if you wanted to measure the voltage at that point. In some designs this takes a considerable amount of time. Now try this with Fig. 4 and notice how much easier it is to locate a point in this circuit. This new design sheet not only helps to locate points for testing, but makes the designing itself much easier and less confusing.

2. Sample Design

A typical design problem is presented here with a step-by-step solution. The particular circuit was selected because the number of components make the design rather difficult and because it demonstrates the compactness that modular construction permits. The circuit (Fig. 1) consists of two stages of amplification with a bridged-T filter between

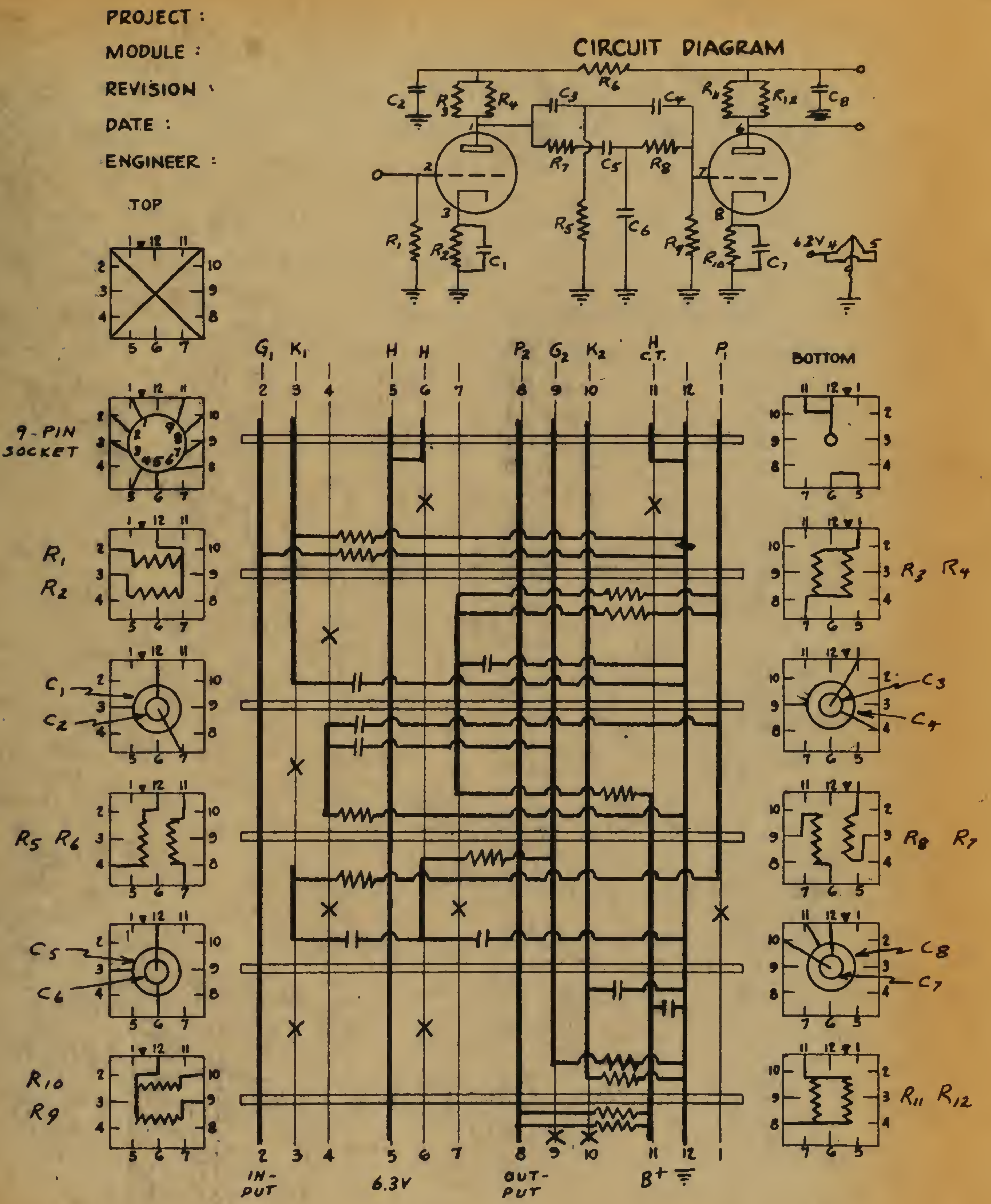

PROJECT :
MODULE :
REVISION :
DATE :
ENGINEER :
CIRCUIT DIAGRAM
TOP
BOTTOM
9-PIN SOCKET
R1 R2
C1 C2
R5 R6
C5 C6
R10 R9
R3 R4
C3 C4
R8 R7
C8 C7
R11 R12
G1 K1 H H P2 G2 K2 H C.T. P1
IN-PUT
6.3V
OUT-PUT
B+

FIG. 1

the two. Only one baseplate is being used in this equipment so the input and output leads will be long, but the frequency is low so this is permissible. Most modules will not contain this many components and therefore will usually be easier to design. For a typical high frequency circuit, see Fig. 4.

As a first step in the design, the circuit diagram is drawn on the design sheet for easy reference. Next, the riser wires that are required to have a definite function are labeled. In this particular circuit, let the input, output, heater, and high voltage wires be assumed to be fixed by the baseplate layout. The tube socket is now drawn on the top wafer and the terminals connected so that the input, output, and heater leads make direct connections. The placement of the other socket leads are not critical. In drawing the components and leads, a colored pencil is helpful in making the circuit stand out on the paper. Before proceeding any further, it is best to examine the circuit more closely, and to lay out a plan of attack, rather than to begin and hope for a solution.

There are eight capacitors and twelve resistors in the circuit, so a minimum of six wafers will be required: one for the tube socket, three for the resistors (four resistors to a wafer), and two for the capacitors (four capacitors to a wafer). Capacitors can have their leads connected to any of the wafer notches, so little difficulty is encountered with the placement of the capacitors. In this design, the capacitors must be stacked, and this brings a restriction. The two stacked capacitors must have a common terminal. Most capacitors have one terminal at ground potential so this restriction usually caused no difficulty. C1 & C2, C3 & C4, C5 & C6, C7 & C8 can be stacked in pairs. When stacking capacitors, the clearance between wafers is decreased, so resistor and

capacitor wafers are usually alternated. This also gives a certain amount of isolation because most of the capacitors have a ground terminal which serves as a ground plane shield between the other components.

With no restrictions imposed by the condensers, the resistors will be examined. Single resistors on a wafer side can be terminated at any pair of notches except those adjacent to the same corner of the wafer. A pair of parallel resistors can be handled the same way, so reference to the design sheet shows that the plate load resistors will give no trouble. This leaves eight resistors whose placement must be investigated. Starting with R1 and continuing in numerical order, the restrictions on the design imposed by each resistor will be listed.

R1 & R2 - To be placed on top of the first wafer. Referring to the wafer drawing, the common terminal (ground for the circuit, can be any spare terminal between 6 and 12

R3 & R4 - These can be seen to give no trouble with any available spare terminal used for the B^+ lead.

R5 - Must go from one free wire to another free wire.

R6 - Must go from wire #4 to a spare wire.

R7 - Must go from wire #2 to a spare wire.

R8 - Must go from wire #6 to a spare wire.

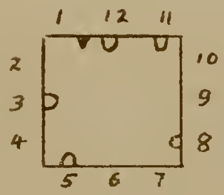
R9 & R10 - Inspection shows that the common terminal (ground for the circuit) can be riser wire 10, 11, 12, 1, 2, 3, 4, or 5

R11 & R12 - These can go directly from #4 to #7 with no difficulty.

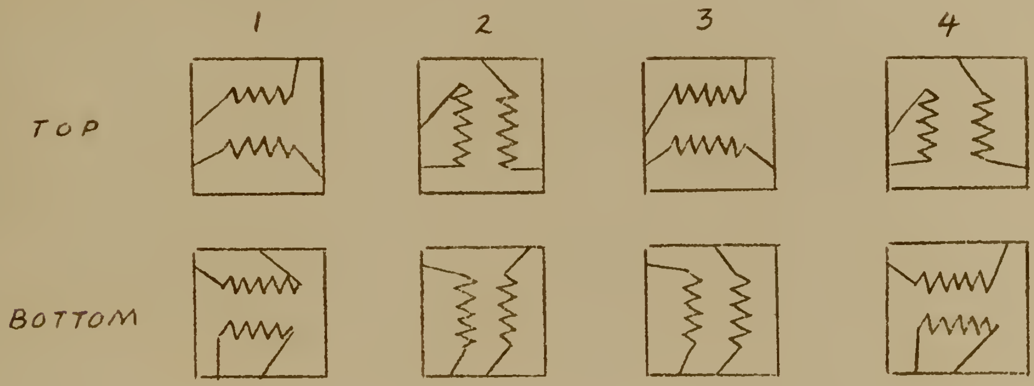
The restrictions on the circuit ground imposed by R1 & R2 and those imposed by R9 & R10 further restrict the circuit ground to either 10, 11, or 12; but riser wire #10 is used for the cathode of tube number two, so

this leaves 11 or 12.

R5, R6, R7, and R8 must be investigated further. A total of five spare wires are needed to meet the above requirements. Wires #5, 8, 11, and 12 are available, and #3 will be available below the third wafer because the cathode circuit of the first tube will be completed above wafer #4. For reference, sketch a wafer and mark the available spare notches as shown below.



Now sketch the top and bottom sides of a wafer and by trial and error find a solution for the placement of the four resistors. Four possible combinations are shown below.



If all the assumptions made above are correct, all that remains of the problem is to place the components on the design sheet, remembering all the restrictions decided on. The complete circuit should be checked and the riser wires cut where necessary. By using this method of investigating each component in the circuit before the final design is started, most of the guessing has been eliminated. To point out the advantage of this preliminary investigation, it is suggested that this design be tried

without the investigation.

3. Special Modulized Circuit Problems

Now that the general problem of design has been considered, it would be well to discuss some of the specific problems that have arisen with various designs. As the range of frequency changes, problems peculiar to the different ranges appear. For the purposes here, it will be sufficient to break the frequencies into two ranges: low frequency range and high frequency range. Some of the problems overlap to a certain extent, such as stray capacity, regeneration, and component placement, and it may be said that the problems increase in number and complexity as the frequency increases. This is true to an even greater degree than with conventional construction.

Low Frequency Range

The discussion for this range is applicable for high gain amplifiers, audio oscillators, counting circuits, power supplies, multivibrators, etc.

In the low frequency range it often becomes difficult to prevent the use of rather large values of capacity. The largest value of capacity available at this time is about 0.03mfd, and these are very unstable, so in practice the largest value normally used is 0.015 mfd. Two of these can be stacked, one on top of another, and one of these stacks can be placed on the top and bottom of a wafer, thus giving a total of 0.06 mfd per wafer. Where wafers are available and where it is necessary to have the larger values of capacity, it can be obtained by paralleling like this, but it is better to avoid it by a circuit change if possible. Where even larger values are required, it is necessary to mount the

capacitor external to the module and bring the leads in on riser wires. This is often done.

Occasionally high voltage differentials will be encountered in a circuit and care should be used to prevent voltage breakdown. Where condensers have been stacked, the clearance between wafers becomes small, so the condenser connections should be made so that the low potential surfaces are facing each other.

Difficulty has been encountered with noise in low level amplifiers because of the plate resistors. Halo tape resistors (finer carbon granules) have to some extent remedied the situation, but these resistors may still generate higher noise levels than the conventional Allen-Bradley resistors, with the noise characteristics becoming worse for the higher resistor values. The tape resistors pass the JAN noise specifications for all values under one megohm.

Regeneration may sometimes be encountered due to coupling between components in the module. One circuit in which this happened is shown in Fig. 2. This double triode audio amplifier had regeneration due to excessive coupling between the input and output condensers. The regeneration could have been decreased by placing the condensers on different wafers and increasing the physical separation, but an extra wafer would have been required, increasing the size of the module. A condenser, C217A, was added to the circuit (with no appreciable effect on the amplifier response) with its grounded side serving as a shield between the input and output coupling condensers. With this new circuit (Fig. 3) the coupling was minimized and all regenerative effects were eliminated. Better planning in the design stage could have prevented this redesign. From Table I below it can be seen that about 4 mmfd. of stray capacity

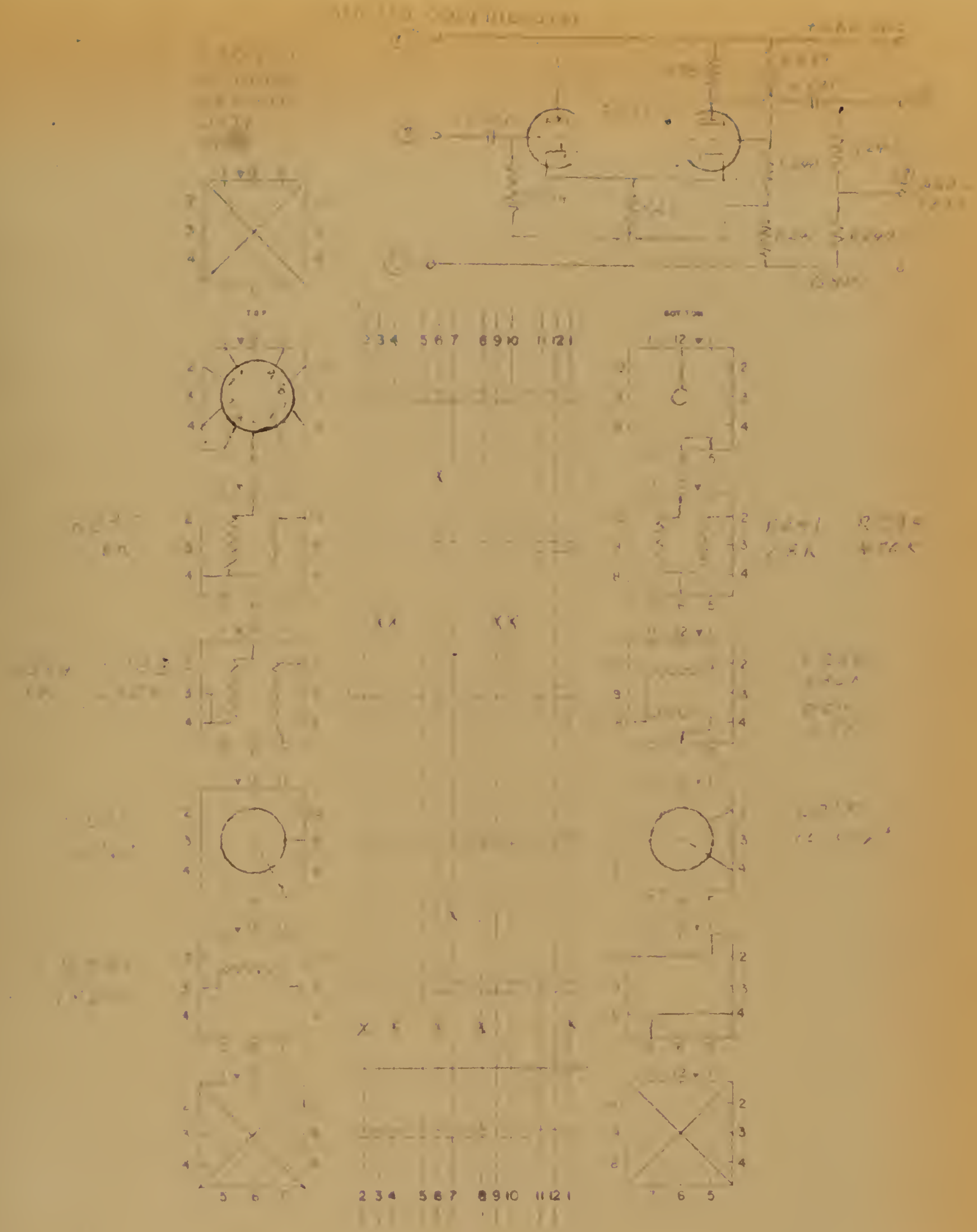


FIG. 2

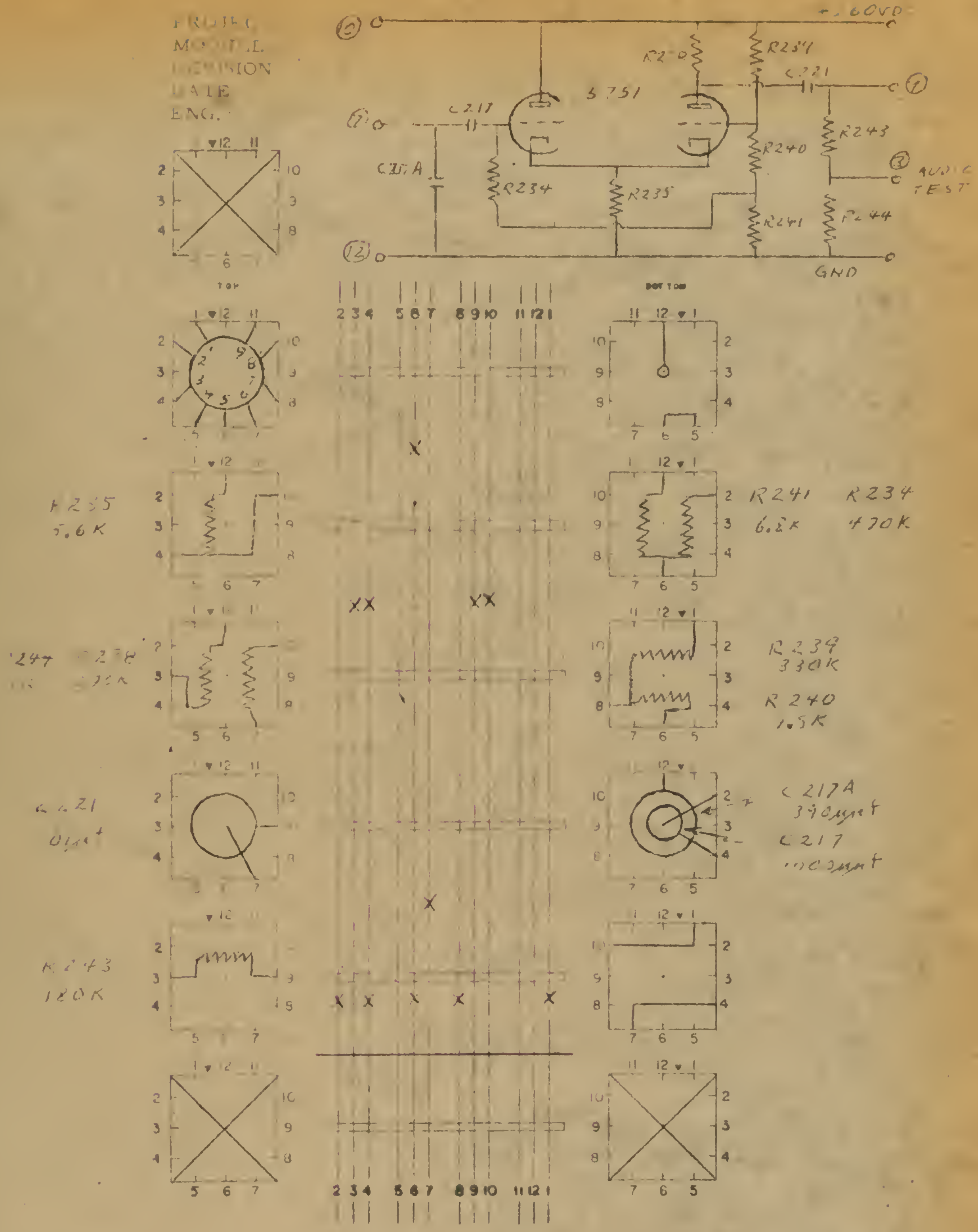

PROJECT
MODULE
REVISION
DATE
ENG.
+160VDC
5751
C217
C217A
C221
R234
R235
R239
R240
R241
R243
R244
AUDIO TEST
GND
TOP
BOTTOM
R235 5.6K
R241 6.8K
R234 470K
R239 330K
R240 1.5K
C221 .01μf
C217A 390μμf
C217 100μμf
R243 180K

FIG. 3

will exist between the two capacitors, and this may be sufficient to cause regeneration. In many cases the capacitors could be relocated, but where this is undesirable, a ground plane (or perhaps an already available bypass condenser) may be inserted between them.

Even though riser wires have a rather small capacity between them, this capacity may add to the other stray capacity and be troublesome. The input and output riser wires should, therefore, be physically separated as far as possible to insure against single stage regeneration. If this separation is not practical, grounded riser wires may be used as shielding elements, and this will decrease the capacity considerably. The following table is given to assist the designer in evaluating the effects of stray capacity while laying out the module.

TABLE I

Source of Stray Capacity	Cap.-mmfd	Remarks
Between two ceramic condensers mounted on top and bottom of adjacent wafers respectively, (3/8" silver screen) nominal wafer spacing	0.7-0.9	Regeneration may result if the condensers involved represent the input and output coupling condensers of a particular stage.
Between any one tube pin (miniature tubes only) and 3/8" silver screen on bottom of adjacent wafer	0.3-0.5	
Between adjacent riser wires.	0.7	The same stray capacity will exist between risers of adjacent modules for an equivalent spacing.
Between alternate riser wires. (Extending along standard 5 wafer module).	0.4	
Between two 3/8" silver screens on top and bottom of adjacent wafer respectively. (Nominal wafer spacing)	0.6-0.7	This also applies to silver screens for resistor tapes where the stray capacity is proportional to the area of the silver.

Between two 3/8" silver screens on top and bottom of same wafer.	4.0-4.5	Also applies to resistor tapes.

Another source of feedback occurs with the connecting leads on the baseplate between modules and power supply leads. Care should be exercised in baseplate layout to minimise stray coupling around one or more stages of a single unit, or between two complete units of a system. The amount of coupling will depend upon the baseplate material used, the length of leads, and the separation between the leads. The following table gives an approximate indication of the magnitude of stray capacity to be expected with the various base materials now in use.

TABLE II

Capacity per Unit Length of Conductor
For Various Base Materials

Capacity (mmfd/inch) - - 1/16 inch line width

Separation (inches)	Phenolic	Epon Fiberglass	Silicon Fiberglass	Teflon Fiberglass
1/16	0.78	0.86	0.73	0.60
3/16	0.50	0.53	0.48	0.40

Ceramic capacitors, particularly in the higher values, change value considerably with temperature. In circuits that are exposed to considerable temperature variations and where the value of capacity is critical, mylar capacitors should be used for the higher values of capacity. In video amplifiers, where a reduction of bypass capacity due to temperature change may tend to give overshoot problems, all bypass capacitors should be of the mylar type.

At the higher frequencies, such as those used in wide range video amplifiers, radiation of the riser wires and coupling between riser wires

of adjacent modules increases. Interstage shielding may become necessary, depending on the gain and physical configuration. The location of load resistors, coupling condensers, peaking coils, etc., should be such as to minimize the total length of lead (riser wire and baseplate connection) between stages.

High Frequency Range

I.F. amplifiers up to 60 mc have been modulized with success and circuits at higher frequencies are undergoing investigation. At these higher frequencies, the interaction between wafers, regeneration, and resonance effects have caused trouble. The problems are of a decidedly more complex nature, and much more difficult to analyze than those found in the low frequency circuits. Modules inherently contain many potential resonant circuits that may cause trouble, and since they cannot be eliminated it becomes necessary to analyze them to make certain that none fall within the passband being used.

In designing for high frequencies, the "hot" R.F. components should be placed as close to the tube socket wafer as possible in order to keep the high potential R.F. leads short. By cutting these riser wires or bypassing them as close to the "hot" component as possible, radiation can be kept to a minimum (see Fig. 4). Interstage connecting leads between modules can be kept short by proper orientation of the module and tube socket. A case of regeneration due to excessive high R.F. potential lead length occurred with the first design of an FM tuner. The connecting leads between two sections of the tuner were made on the baseplate in order to be able to plug-in the different units. This necessitated long "hot" leads running the full length of the first module of one

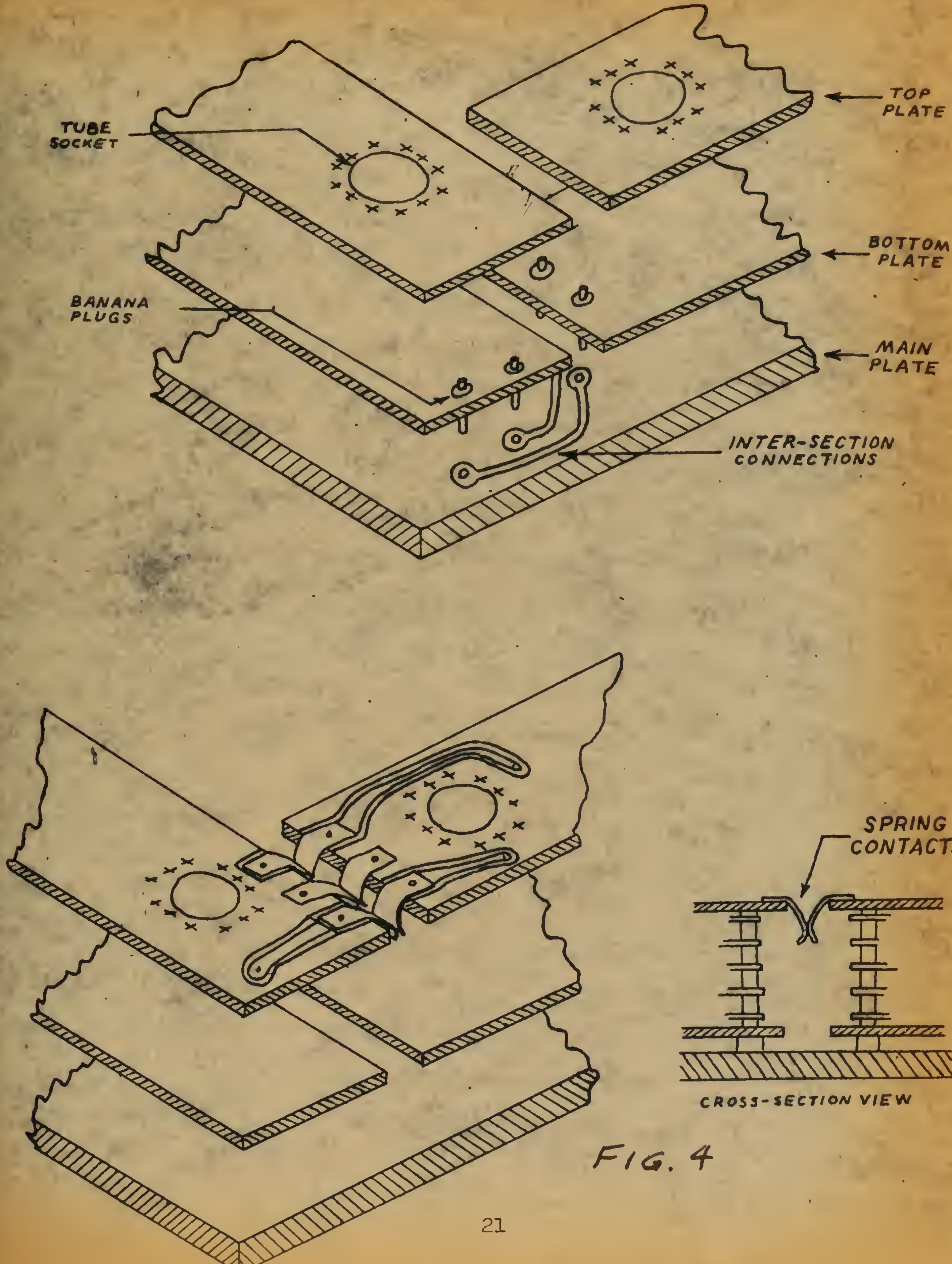

TUBE SOCKET
TOP PLATE
BOTTOM PLATE
BANANA PLUGS
MAIN PLATE
INTER-SECTION CONNECTIONS
SPRING CONTACTS
CROSS-SECTION VIEW

FIG. 4

section and the last module in another section. The problem was solved by using spring contacts on the top baseplate to make the connections between the sections (Fig. 5). Even with short leads, the modules will usually have to be shielded individually to prevent regeneration.

All the precautions pertaining to the separation of input and output riser wires and separation of components to prevent feedback in low frequency amplifiers apply equally as well to the higher frequency range. Where copper etched coils are mounted in the module, this is of particular importance. Here again, a ground plane, in the form of a condenser with one side grounded, may be used to shield the etched coil from the other components in the module.

The grid-to-plate capacity may be minimized by placing the grid circuit components in the previous module, but even then, precautions must be taken. The stray capacity between the grid tube pin connector and an etched coil mounted on the bottom of the adjacent wafer may be as high as 0.6 mmfd. This relatively high grid-to-plate capacity may easily cause regeneration around a single stage of an amplifier. Reducing the size of the coil as much as possible and offsetting the coil as far as possible from the grid pin may decrease the capacity sufficiently to prevent regeneration. The coil should be oriented such that the outside turns are at a low RF potential. If, after these precautions are taken the capacity is still to great, the coil can be moved down to another wafer even at the expense of making the lead slightly longer. Locating the load resistor of the preceeding stage on the back of the wafer containing the tuning coil or load resistor of the succeeding stage will usually create an even higher grid-to-plate capacity. One design that proved to be unsatisfactory because of excessive grid to plate

PROJECT : FM TUNER

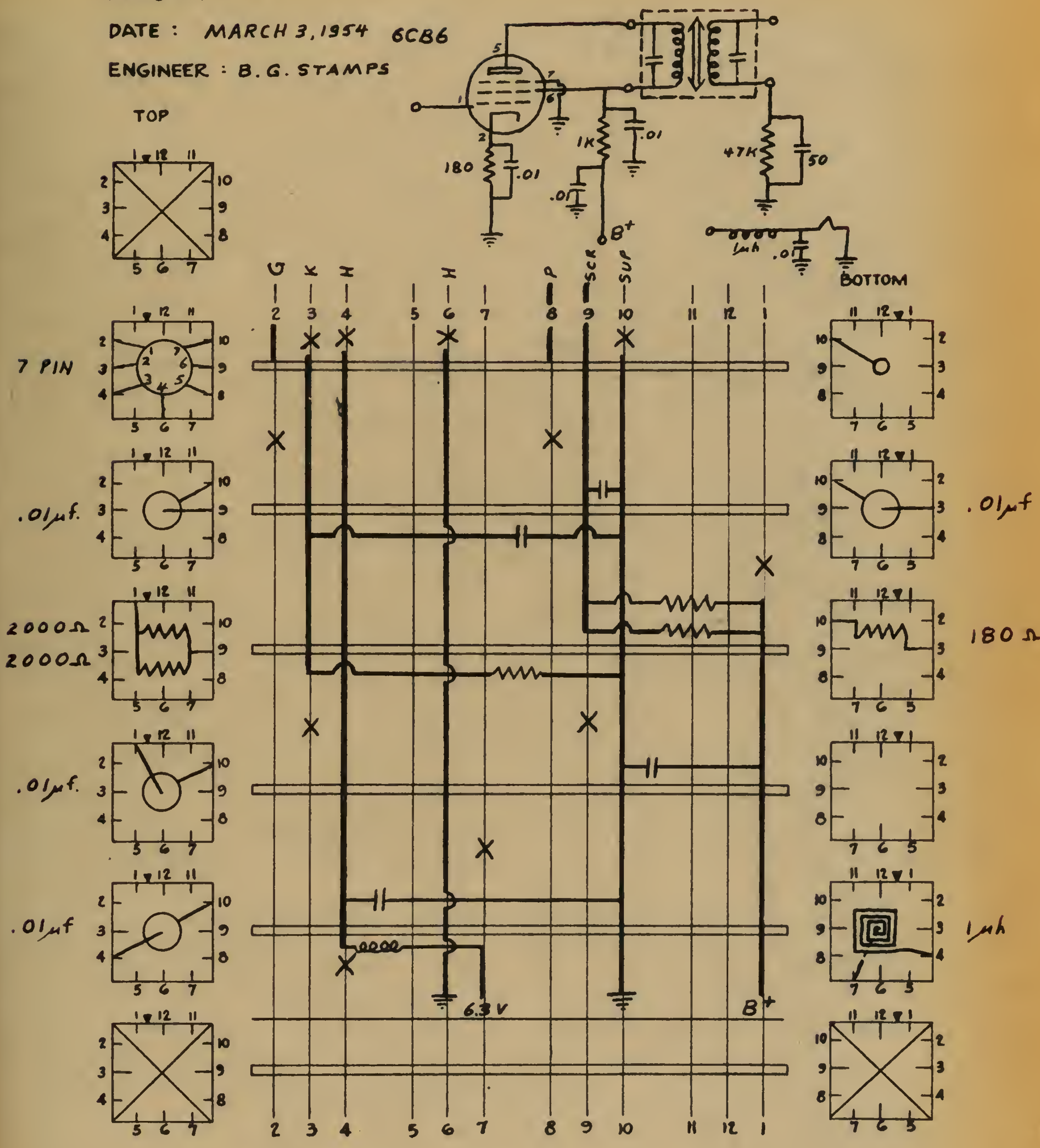
MODULE : IF AMPLIFIER

REVISION : 1

DATE : MARCH 3, 1954

ENGINEER : B. G. STAMPS

CIRCUIT DIAGRAM



NOTE: B+ DROPPING RESISTORS ARE
10 K EACH IN 1ST + 2ND IF AMPLIFIERS.

FIG. 5

capacity is shown in Fig. 6. The difficulty was eliminated by following the above procedure of decreasing the size of the coil, moving it away from the grid, putting the grid resistor in the previous module, and insuring that the outside turns were at a low R.F. potential. The new design is shown in Fig. 7.

The same problem arises in the design of high gain-maximum bandwidth R.F. amplifiers that occurs in the design of high gain video amplifiers. The interstage and intrastage stray capacity must be kept to a minimum. The sources of stray capacity listed in Table I and the baseplate capacities listed in Table II also apply here. In addition, if printed coils are used as interstage tuning coils or peaking coils, the following table will be useful.

TABLE III

Source of Stray Capacity	Cap.(mmfd)	Remarks
Between surface of etched coil on top of one wafer and 3/8" silver screen on bottom of wafer below coil wafer.	0.5-0.7	Six turn coil, 0.10" wire, 0.10" spacing Inner coil terminal at exact center.
* Between any tube pin connector (miniature type tubes only) and surface of etched coil on bottom of same wafer.	0.8-1.0	"
* Between any tube pin connector and surface of etched coil on bottom of adjacent wafer.	0.4-0.6	"
Between surface of etched coil and 3/8" silver screen on bottom of same wafer.	2.5-2.9	"
Between surface of etched coil on top of one wafer and 3/8" silver screen on top of wafer below coil wafer.	0.8-1.2	"

* This effect may be extremely undesirable. If several tube pins are at low R.F. potential, the total shunt capacity may be extremely high.

PROJECT :

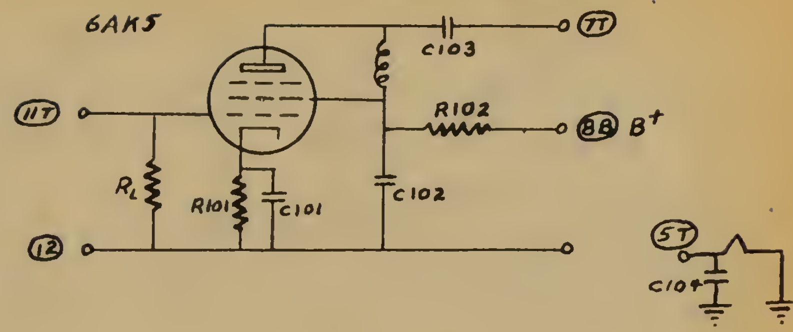
MODULE :

REVISION :

DATE :

ENGINEER :

CIRCUIT DIAGRAM



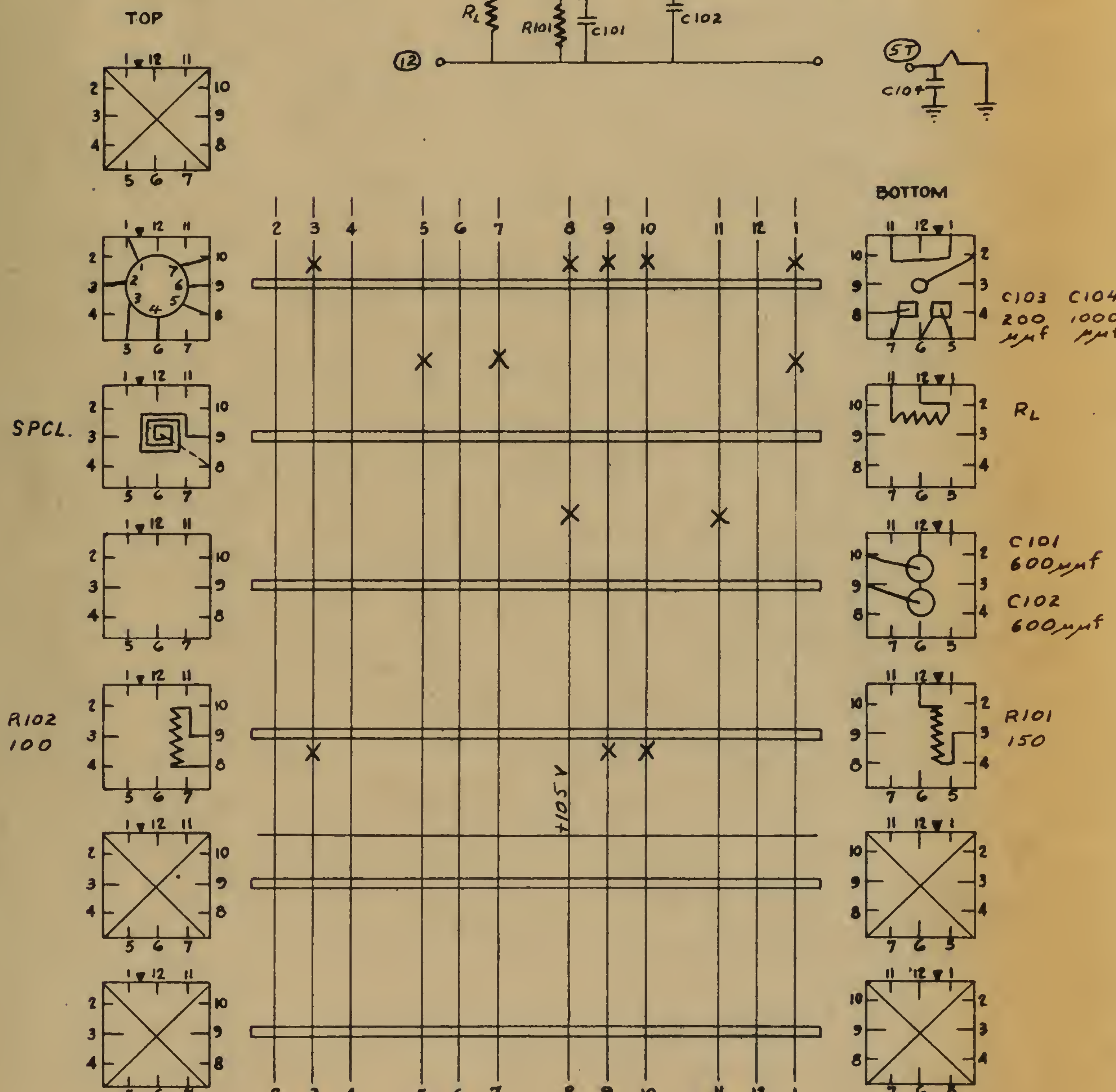


FIG. 6

PROJECT :

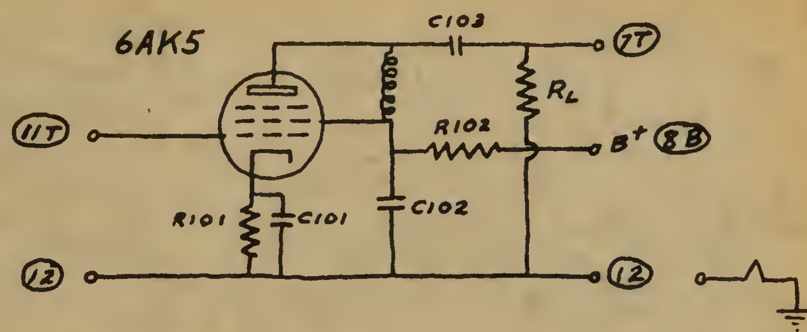
MODULE :

REVISION :

DATE :

ENGINEER :

CIRCUIT DIAGRAM



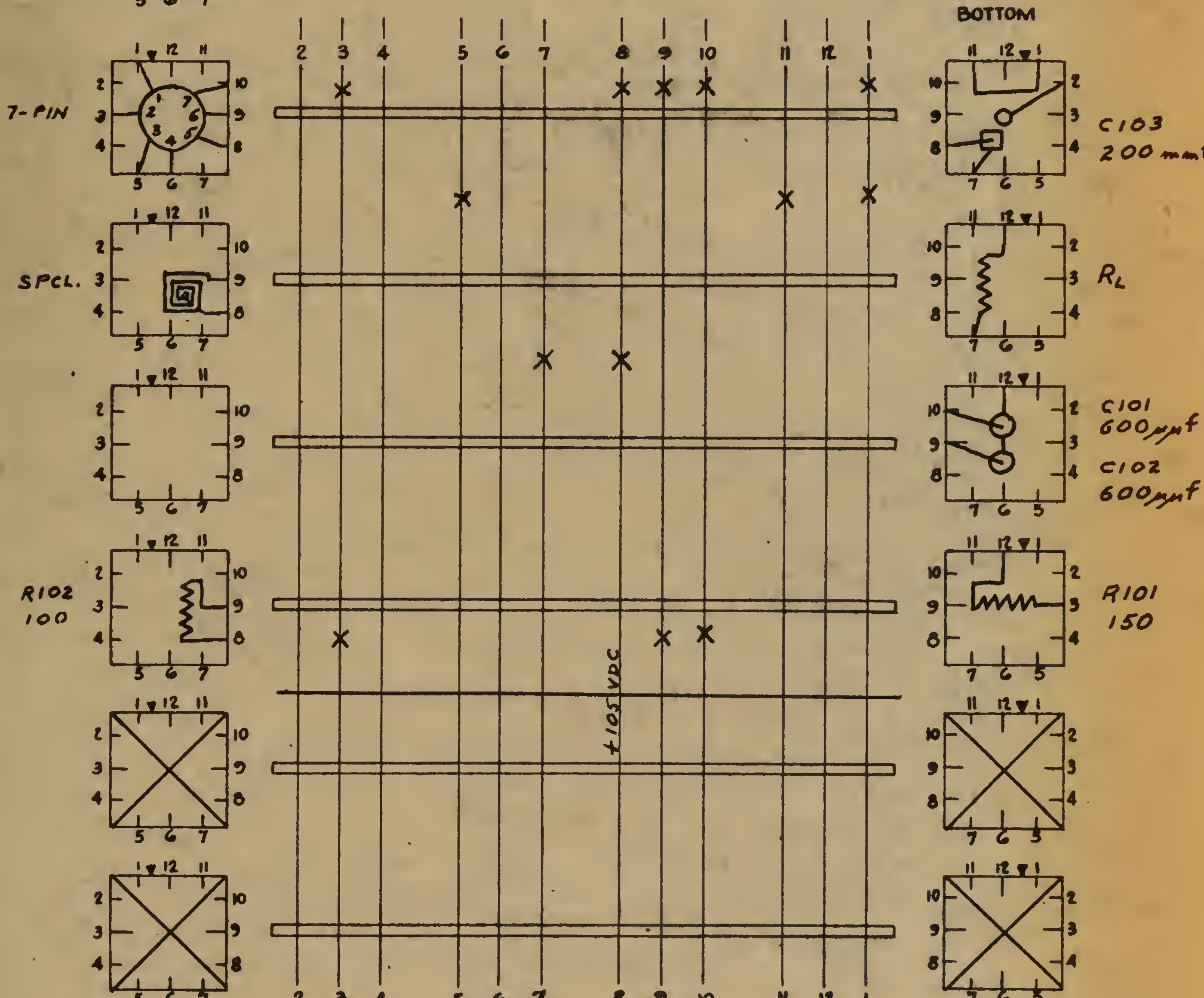


FIG. 7

The Q of printed coils is a function of width, spacing and thickness of the conductor, and of the base material used. The table below gives an approximate indication of the effects on the coil Q of varying the dimensions.

TABLE IV

Coil Dimensions (Inches)	Inductance (Microhenries)	Q
.005 wide .010 spacing .001 thickness	1.14	50
.010 wide .010 spacing .001 thickness	0.94	65
.010 wide .010 spacing .003 thickness	0.91	76

Note: All coils 8 turns; XXXP base material. Outer coil terminal fixed; inner coil terminal brought closer to center to maintain same spacing for a greater conductor width. For inductance formulas of flat rectangular coils, refer to Terman's Radio Engineer's Handbook, page 59.

The effects of various base materials on the Q of coils as a function of frequency is given below.

TABLE V

Freq.	XXXP	Teflon Fiberglass	Silicone (G-7) Fiberglass	Epon Fiberglass
10	36.3	37.0	42.6	43.3
25	62.5	62.7	64.0	64.7
50	80.0	79.0	78.3	80.3
100	114.0	116.5	112.7	113.0

It is seen that the base material has a comparatively small effect on the Q of the coil. Coils printed on the same base material tend to vary by as much as 10%, which is greater than the variation with base material. These variations are due to the non-uniformity of the copper conductor and to oxidation which occurs with age and environment. The coil Q's may be increased by as much as 10% and the oxidation prevented by silver plating the coils.

Mounting condensers or resistors on the opposite side of a wafer containing a printed coil seriously affects the Q and inductance of the coil. A 3/8 inch silver screen is sufficient to reduce the Q by 20% and the inductance by 10%. Because the silver screensto which the tape resistors are attached have a similar effect, it is customary to mount only the corresponding load resistor on the same wafer with the etched coil and if possible to space it from the coil.

The distributed capacity of a copper etched coil of 0.010" width, 0.010" spacing, 0.001" thickness, and mounted on XXXP base material, will be from 0.8 to 1.0 mmfd. This capacity varies as the dielectric constant of the base material used.

Modules, because of their physical configuration, inherently contain many resonant circuits. Many of these absorption traps can be attributed to the parallel riser wires acting as transmission lines, either terminated or unterminated. The lengths are short, so the resonant frequencies are high. If two adjacent or alternate riser wires are shorted at one end, the line presents an inductive reactance at all frequencies up to:

$$f\ (\mathrm{mc}) = \frac{(7.5)\ (10^3)}{L}$$ where L is the length of line in centimeters

The value of this inductance, of course, depends on the length of line and spacing between the risers.

Any stray or actual capacity across the line formed by the risers will form a resonant circuit whose natural frequency may fall within the passband of the circuit involved, seriously affecting the response. An example of such a resonant circuit occurred in the module shown in Fig. 6. The filament riser wires #5 and 6 form the line, the filament shorts one end of the line, and the filament bypass condenser, C104, completes the circuit. This circuit was detuned by grounding the low side of the filament bypass condenser to riser wire #2. It was later found that the filament bypass was not required.

The surge impedance of two adjacent riser wires with standard spacing of 0.2185 inches is:

$$Z_o = 276 \log \frac{(2)(0.2185)}{0.030} = 320 \text{ ohms}$$

and for alternate riser wires with a spacing of 0.437 inches is:

$$Z_o = 400 \text{ ohms}$$

In order to get a feeling for this resonant effect, the following table is given which lists the value of capacity with which a 0.50 inch long line will resonate at a particular frequency.

TABLE VI

D = 0.2185 inches			D = 0.437 inches		
Adjacent Risers			Alternate Risers		
FREQ. (mc)	XL (ohms)	C (mmfd)	FREQ. (mc)	XL (ohms)	C (mmfd)
60	4.8	552	60	6.0	444
120	9.6	138	120	12.0	111
240	20.8	32	240	26.0	25
480	41.6	8	480	52.0	6

It can be seen from the above table that the resonant effects may not only cause trouble in RF amplifiers, but may create absorption traps in high frequency IF amplifiers as well. The resonant frequency may be moved out of the passband of the amplifier by;

1. Varying the length of the line
2. Varying the spacing of the line
3. Varying the capacity across the line (If this capacitor is of the ceramic type, detuning the line by varying this component should be undertaken with care because the relatively poor temperature stability of these condensers may cause the resonant frequency to drift back into the passband at certain temperatures).

CHAPTER III

COMPONENT STUDY

1. Mylar Capacitors

A. Construction

Mylar capacitors were first constructed of alternate layers of aluminum foil and mylar dielectric having a thickness of .0025 or .0050 inches. Small pinholes in the dielectric decreased the voltage safety factor in many cases and made the condensers unreliable. This condition has been corrected in later capacitors by using two layers of the mylar dielectric, thus staggering the flaws. After winding, tabs are spot welded to the two ends of the foil, giving an inductively wound capacitor. Non-inductive capacitors have been made by cementing the edges of the foil with silver paste, but the process is time-consuming and unreliable. A method will no doubt be found to manufacture these easily, but until this is possible, the mylar capacitors can only be used in circuits where the inductive qualities will not be harmful. After the capacitor is wound and the tabs attached it is stuck to the wafer with a coating of Hysol 6020 impregnant, and the tabs, which are on opposite ends, are carried to the appropriate notches. The same impregnant is then used to cover the entire capacitor as a protection against moisture absorption and handling damage.

B. Qualification for JAN Specifications

The mylar capacitors meet all JAN-C-25 specifications except for being encased in a metallic or composition case. Because of the special size requirements of the capacitor to make it compatible with the modular type construction, it does not fall in any exact JAN specifications catagory.

C. Temperature Coefficient

The temperature coefficient of the mylar capacitor is comparable with that of the better grades of paper capacitors. Fig. 8 shows the capacity change versus temperature for the mylar capacitor and for the Sprague "Vitamin Q" capacitor. The curve for the mylar capacitor was drawn from an average of readings taken with 12 mylar capacitors (.025 mfd. with a double .025 inch mylar layer, 19 turns wound on a large arbor). The capacity change with various capacitors in the group was very uniform with the maximum capacity change just slightly higher than the average. The curve is applicable to all mylar capacitor values from 2400 mmfd to .025 mfd.

D. Dissipation Factor

The dissipation factor is less than 1% from 10°C to 110°C and is less than 1.5% over the range of -55°C to 125°C. Fig. 9 shows a curve of dissipation factor versus temperature for the mylar and the Sprague "Vitamin Q" capacitors.

E. Salt Spray

Protective coatings using both Hysol 6020 and Hysol 6101 provide good protection against damage by handling and corrosion. Application techniques are critical, however, since any small break in the coating will allow the exposed surface to be attacked. The corners and edges are the critical points to watch. A minimum of two coats of resin should be used and the coated wafers baked in a horizontal position. This coating affords good protection against humid atmosphere as well. Insulation resistance of mylar capacitors is in excess of 20,000 megohms normally and even when exposed to 2000 hours of 90-95% relative humidity, provided the impregnation technique is satisfactory.

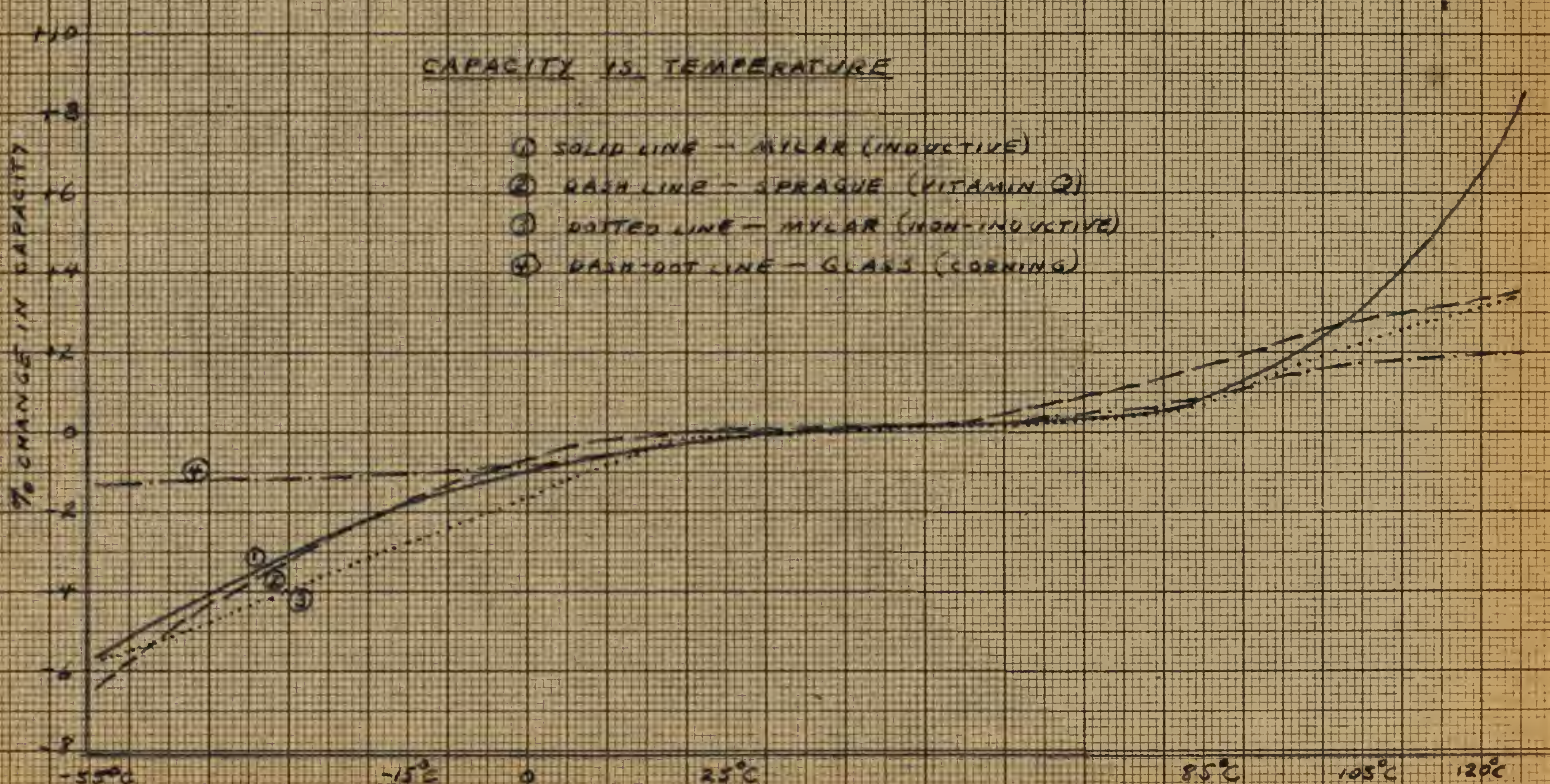

CAPACITY VS. TEMPERATURE
① SOLID LINE — MYLAR (INDUCTIVE)
② DASH LINE — SPRAGUE (VITAMIN Q)
③ DOTTED LINE — MYLAR (NON-INDUCTIVE)
④ DASH-DOT LINE — GLASS (CORNING)
% CHANGE IN CAPACITY
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-55°C
-15°C
0
25°C
85°C
105°C
120°C

FIG. 8

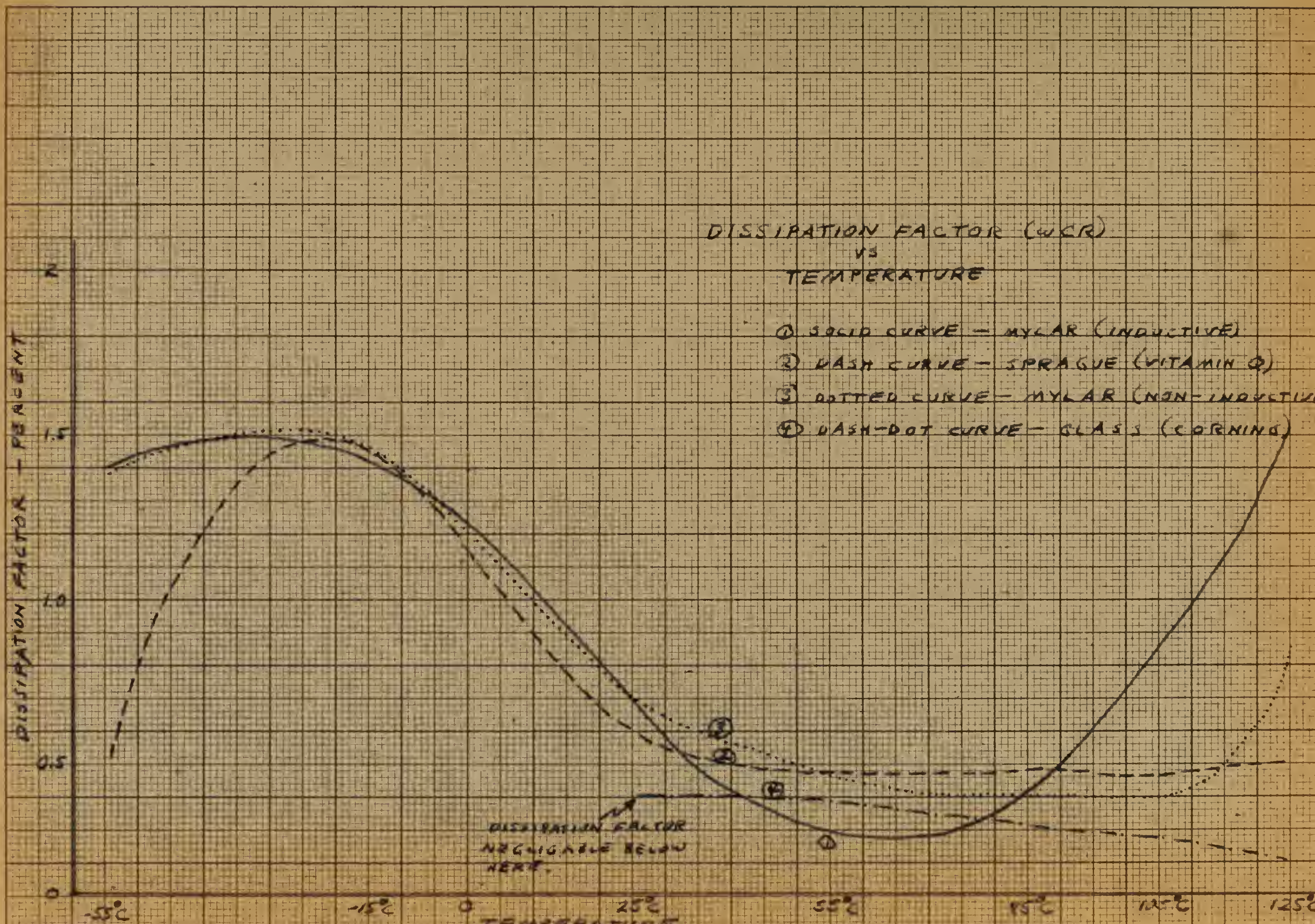

DISSIPATION FACTOR (WCR)
VS
TEMPERATURE
① SOLID CURVE — MYLAR (INDUCTIVE)
② DASH CURVE — SPRAGUE (VITAMIN Q)
③ DOTTED CURVE — MYLAR (NON-INDUCTIVE)
④ DASH-DOT CURVE — GLASS (CORNING)
DISSIPATION FACTOR NEGLIGABLE BELOW HERE.
DISSIPATION FACTOR — PERCENT
2
1.5
1.0
0.5
0
-55°C
-15°C
0
25°C
55°C
85°C
105°C
125°C
TEMPERATURE

FIG. 9

F. Voltage Ratings

Mylar capacitors are conservatively rated at 300 VDC for all values from 2400 mmfd to 0.1 mfd. Life tests as per JAN-C-25(F-18) consisting of 250 hours of continuous operation at rated voltage in an 85°C oven have been successfully passed.

G. Operation in Rarefied Atmosphere

Mylar capacitors have successfully passed the JAN-C-25(F-10d) test consisting of operation for a minimum of one minute at 3.4 inches of mercury (corresponds to an altitude of 50,000 feet) with an application of 125% of rated voltage.

2. Ceramic Capacitors

The ceramic capacitors used with modular construction are made by firing silver electrodes onto flat discs of ceramic. The ceramic bodies are made of titanium dioxide combined with various oxides to change the dielectric constant of the bodies. By changing the composition of the dielectric, dielectric constants from 10 to 7300 may be had. The following formula may be used to roughly calculate the capacity to be expected from a capacitor.

Silver extending to the edge

$$K = \frac{Cxtx5.66}{d^2}$$

Equal electrodes not extending to the edge

$$K = \frac{C \times t \times 5.66}{(d + t)^2}$$

Unequal Electrodes

$$K = \frac{C \times t \times 5.66}{(d_1 + t)^2}$$

where K = dielectric constant

C = capacity in mmfd

d_1= smaller electrode diameter

d = electrode diameter

t = thickness of body

The silver electrodes can be varied from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter and therefore the capacity can be varied over nearly a four to one range while still using the same type ceramic body. By selecting the body with the correct dielectric constant and adjusting the size of the electrodes, ceramic capacitors can be made from 5.1mmfd to 0.015mfd. The ceramic bodies come in a wide range of temperature coefficients, so the body used will also be affected by the temperature coefficient desired or required.

Ceramic dielectrics have been divided into two general classes according to their temperature characteristics. Class I bodies are characterised by high Q and good dielectric stability with temperature. These bodies are therefore suitable for use in resonant circuits and other applications where good stability is required. Class II bodies are characterised by high dielectric constants, but are not nearly as stable as the Class I bodies. These bodies are suitable for bypass and coupling applications where high Q and capacity stability are not so important.

A. Class I Ceramics

1. Range of K values: 6 to 600
2. Range of temp. coeff.: P120 to N5600
3. Range of capacity: 6 to 800 mmfd

Some of the Alsimag body numbers, their temp. coeff., dielectric constants, and capacities available with a silver screen of 7/16 to 1/2 inch in diameter are given below.

Body No.	Temp. Coeff.	K-value	Capacity range
T-83	P-100	K16	14 to 46 mmfd
T-96	NPO	K30	22 to 75
T-96	N610	K70	52 to 195
T-109	N1400	K135	103 to 355

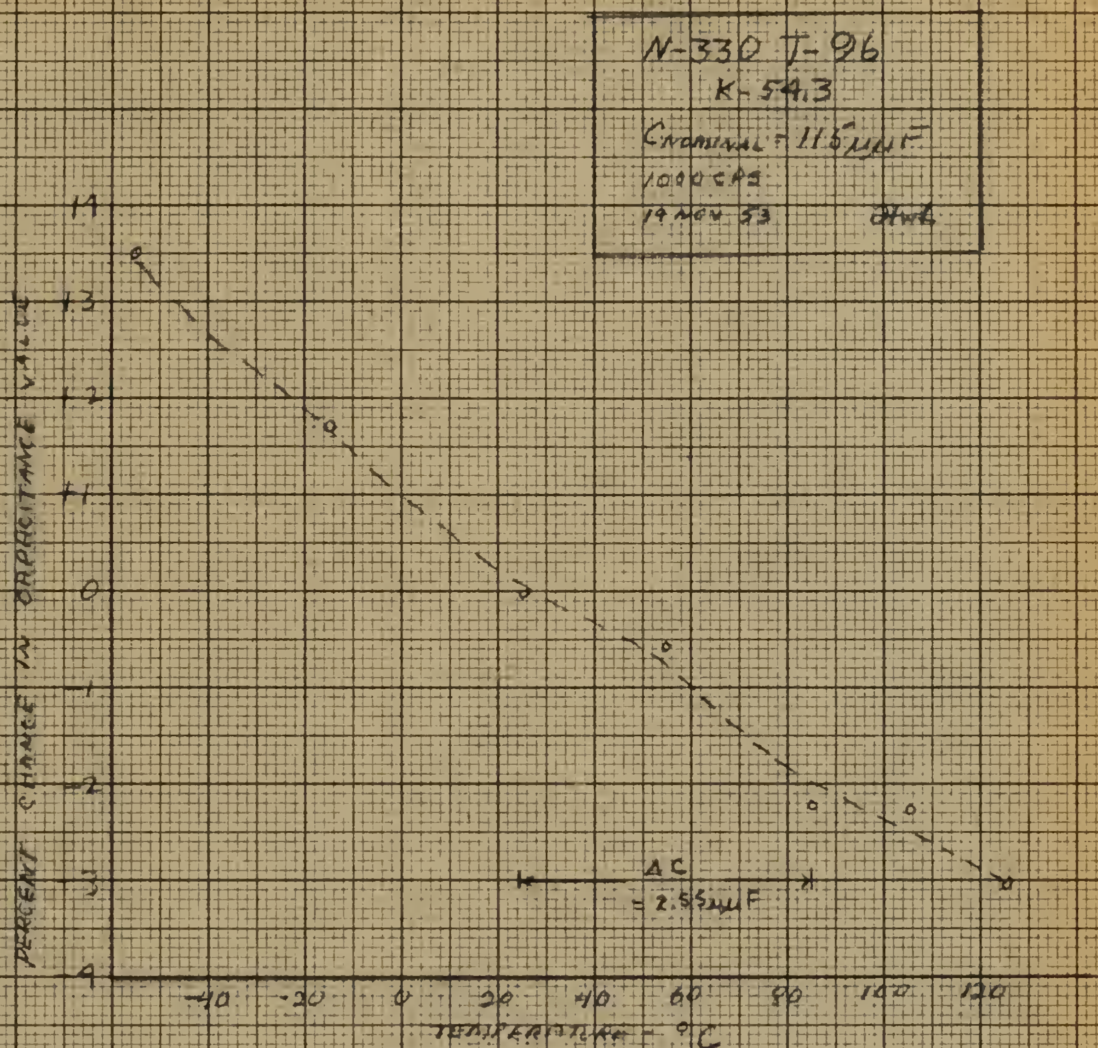
4. Preferred values of temperature coefficient

T-83 series		T-96 series	
P-120	K15	NPO	K30
P-100	K16	N030	K31
P-030	K17	N080	K36
NPO	K19	N150	K41
T-109 series		N220	K45
N1400	K135	N330	K50
		N470	K60
		N750	K82

The temperature characteristics given above only hold over the temperature range from 25°C to 85°C. The characteristics may vary outside this temperature range, as shown in Fig. 10. This curve is for a T-96 body N330 K54.3, with a nominal capacity of 120 mmfd. It would be well to consider this variation of temperature coefficient as shown in the curve if operation over a wide range of temperatures is contemplated. The same curve of temperature coefficient versus temperature is given for T-110 bodies in Figs. 11, 12, and 13 to show that all bodies do not give the same characteristics outside the specified range.

Q Value

The Q of the ceramic Class I condensers when mounted on steatite wafers compares favorable with that of a commercial ceramic capacitor (Cornell-Dubllier 110 mmfd). The test capacitors were made of T-96



$$T.C. = \frac{C_{25} - C_{85}}{C_{25}} \times \frac{10^6}{T_1 - T_2} = -\frac{2.55}{115} \times \frac{10^6}{60} = N370\ ppm/{}^\circ C$$

FIG. 10

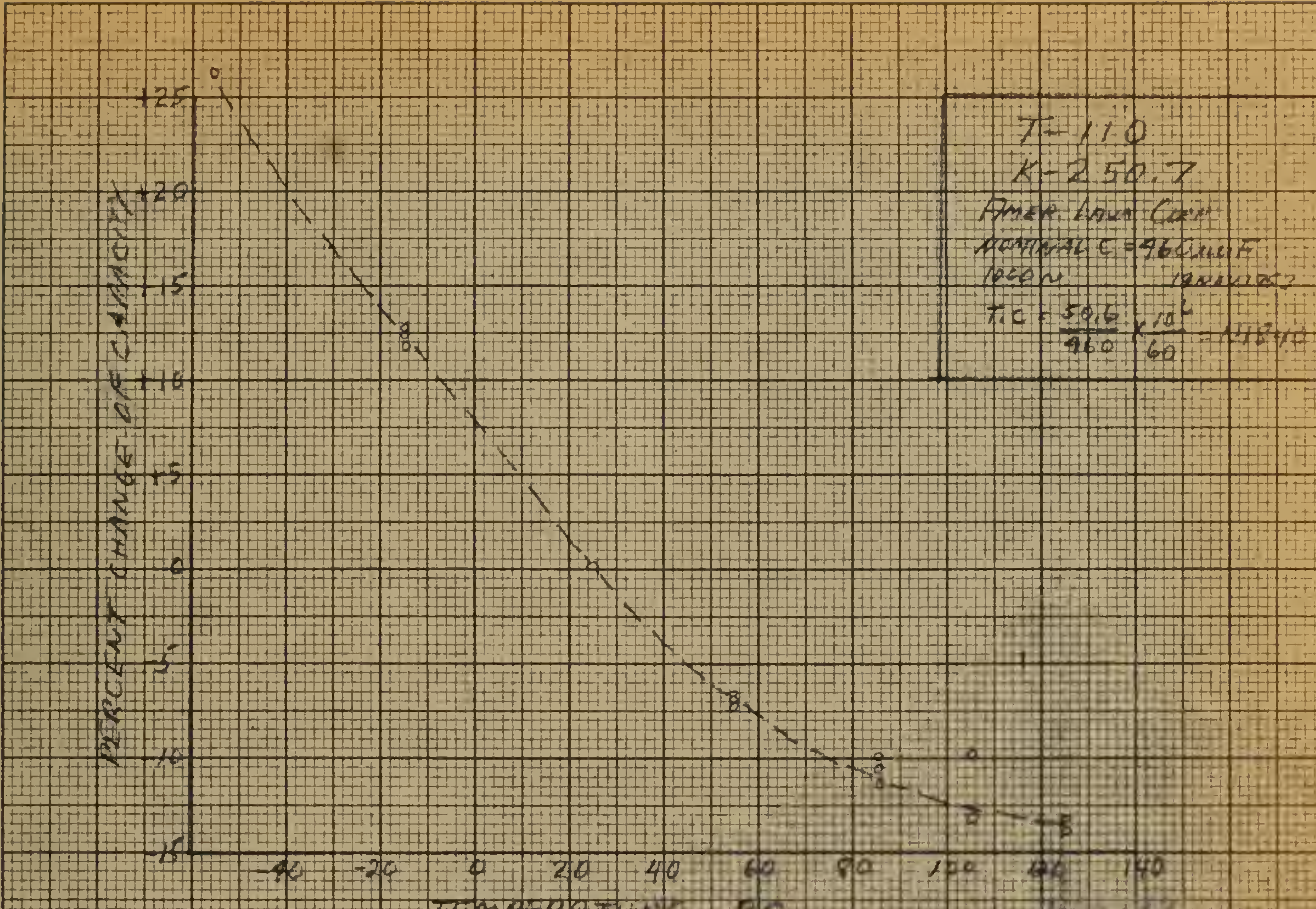

T-110
K-250.7
AMER. LAVA CORP
PERCENT CHANGE OF CAPACITY
TEMPERATURE - °C

FIG. 11

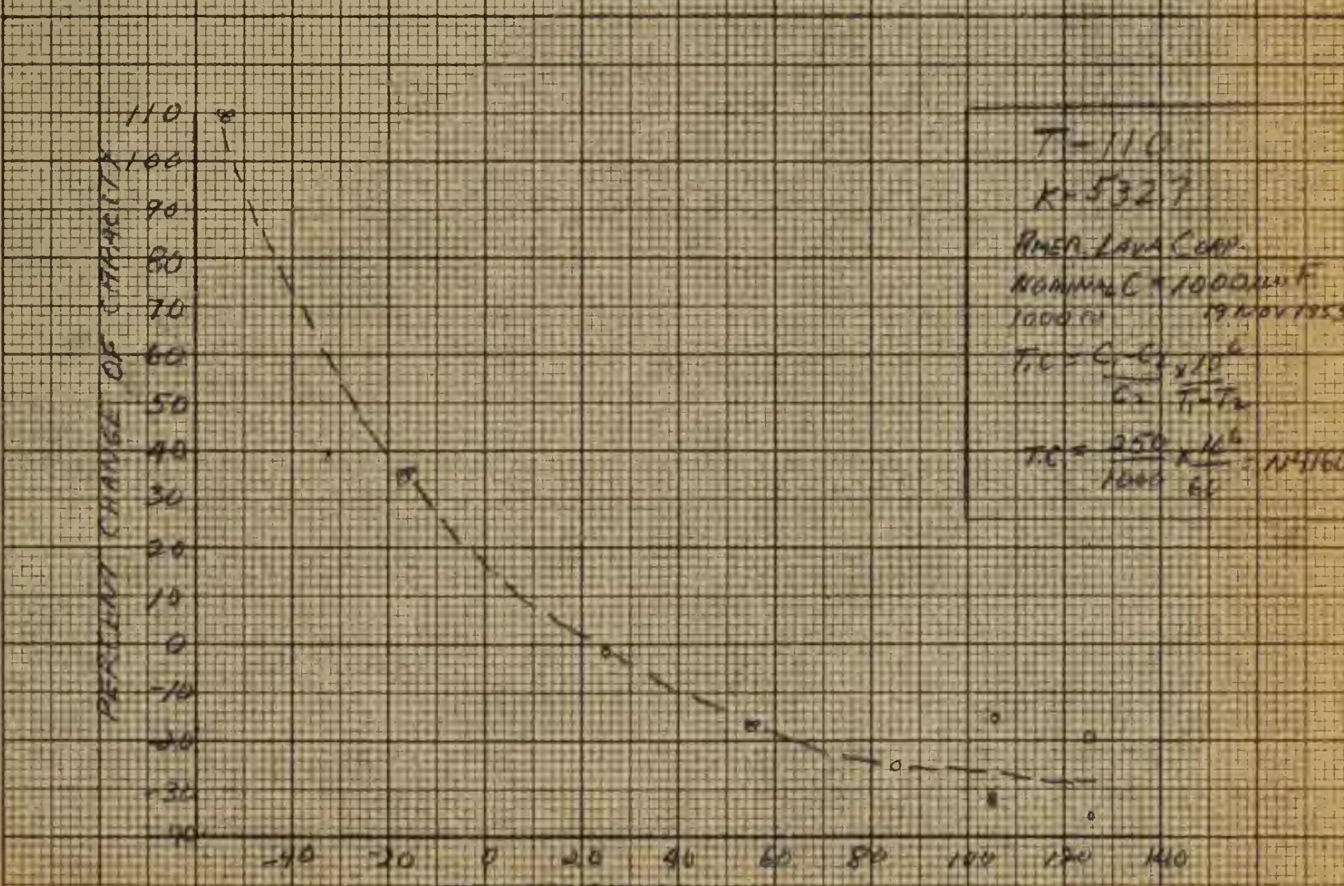

T-110
K-532.7
AMER. LAVA CORP.
19 NOV 1953
PERCENT CHANGE OF CAPACITY
TEMPERATURE - °C

FIG. 12

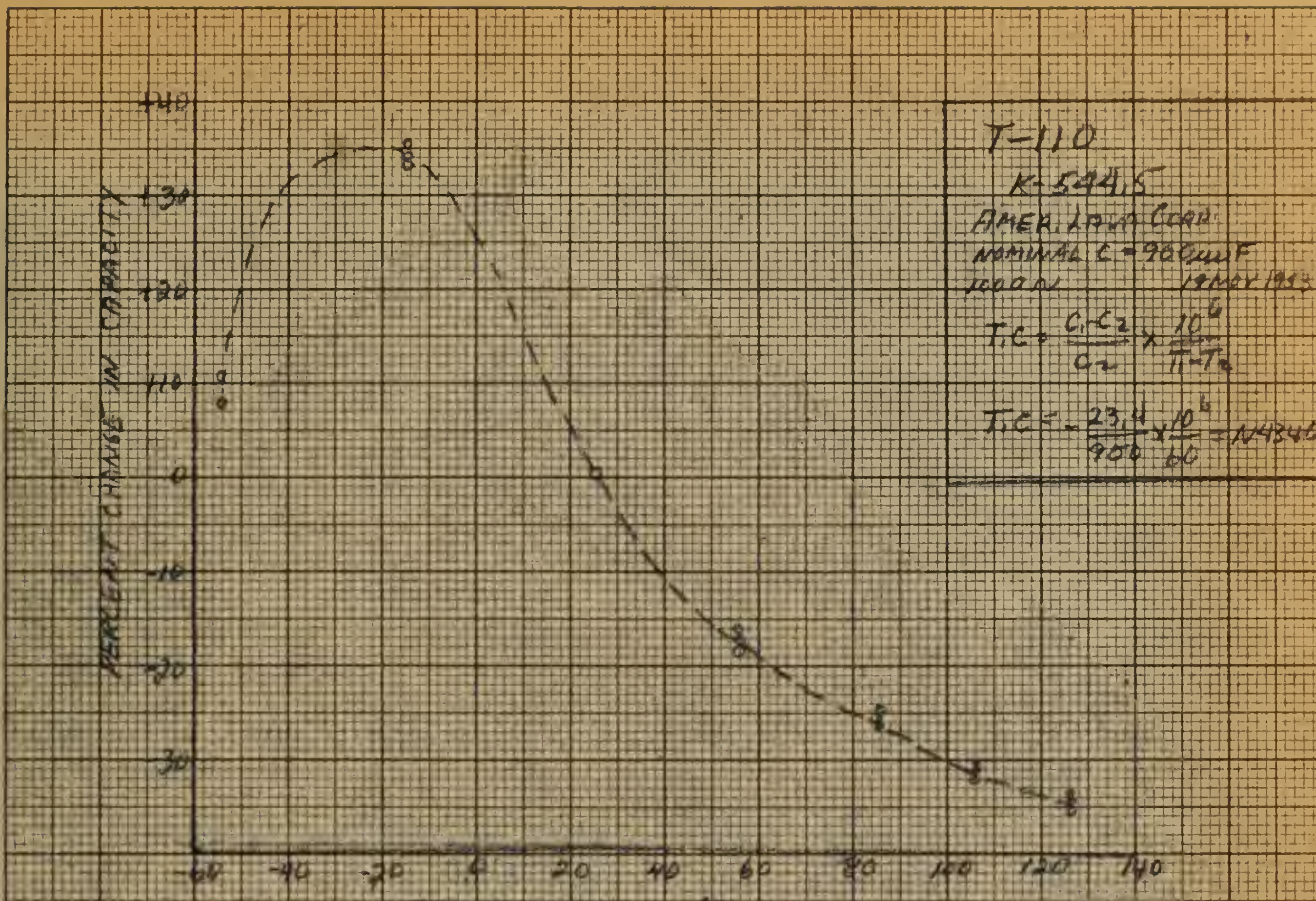

T-110
K-544.5
AMER. LAVA CORP
NOMINAL C = 900 μμF
PERCENT CHANGE IN CAPACITY
TEMPERATURE - °C

FIG. 13

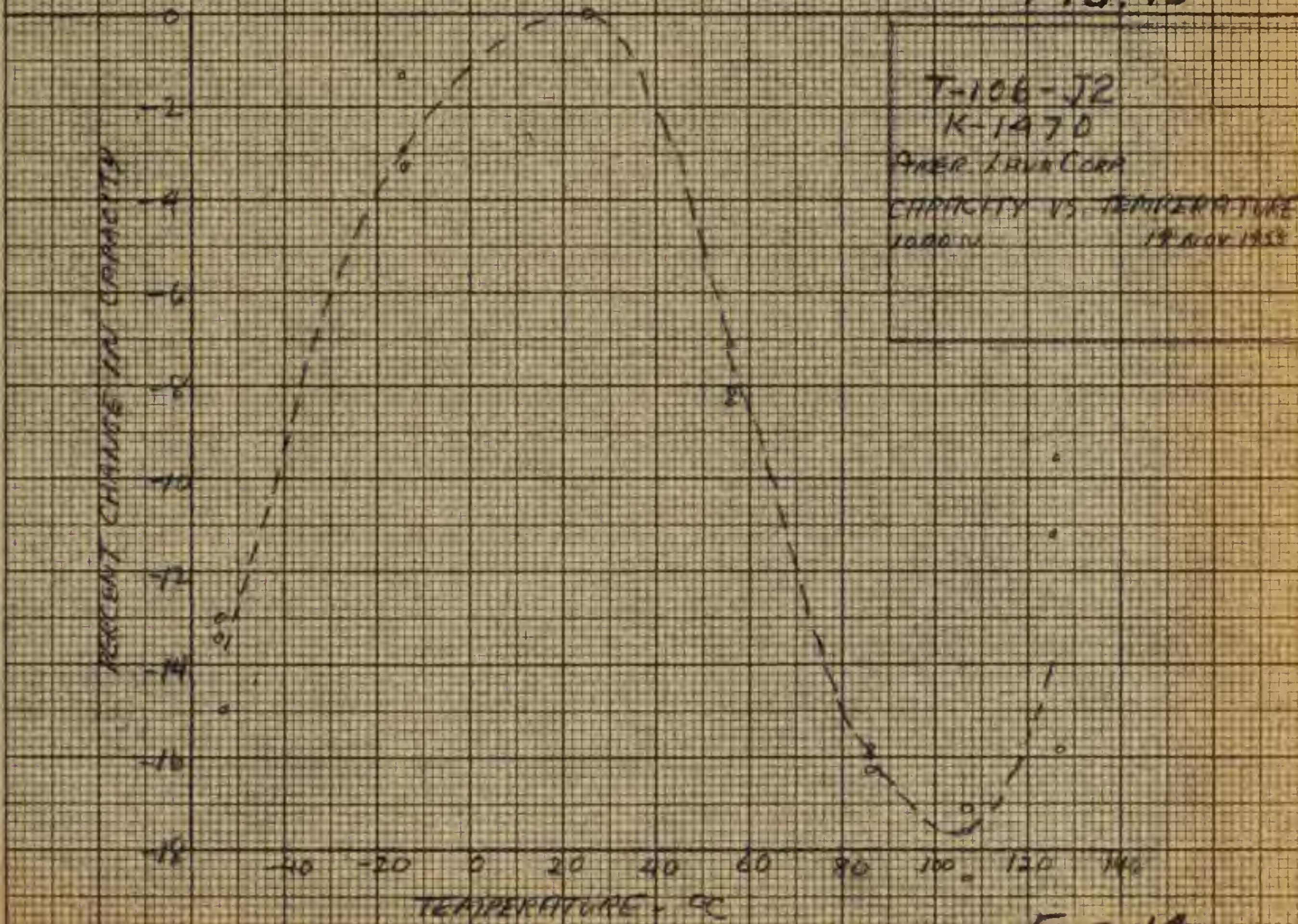

T-106-J2
K-1470
AMER. LAVA CORP
CAPACITY VS. TEMPERATURE
PERCENT CHANGE IN CAPACITY
TEMPERATURE - °C

FIG. 14

K65.9 bodies having a capacity of 110 mmfd and mounted on a steatite wafer.

T-96 body:	Q = 127-132 at 30 mc
C-D capacitor:	Q = 132-136 at 30 mc

Decay Characteristics

The decay of K in Class I bodies is less than 1% for a 100 hour period for K values under 500 and less than 1.5% for K values above 500.

B. Class II Ceramics

1. Range of K Values: 250 to 7000

2. Range of capacity: 150 mmfd to 0.015 mfd

By using 7/16" to 1/2" diameter screened electrodes, the following values of capacity have been obtained:

Body number	Capacity range (mmfd)
T-133-B	160 to 670
T-145-A	315 to 1200
T-106-J	820 to 3200
T-137-A	1270 to 4680
T-128-A	3600 to 13,000

Temperature coefficient characteristics of the Class II bodies vary considerably as shown in Fig. 14 through Fig. 16. These curves are not to be assumed to be exact, and in fact will vary with different lots of the same body number. The peak of capacity does not always fall at the same temperature for a given body number, but it does lie within a certain range of temperatures. According to manufacturers' specifications, the temperature ranges of the K peaks are as follows:


T-111-4
K-3650
AMER. LAVA CORP.
CAPACITY VS. TEMP.
1000 CYCLES
19 NOV 53
PERCENT CHANGE OF CAPACITY
TEMPERATURE - °C
0
-10
-20
-30
-40
-50
-60
-70
-40
-20
0
20
40
60
80
100
120
140

FIG. 15

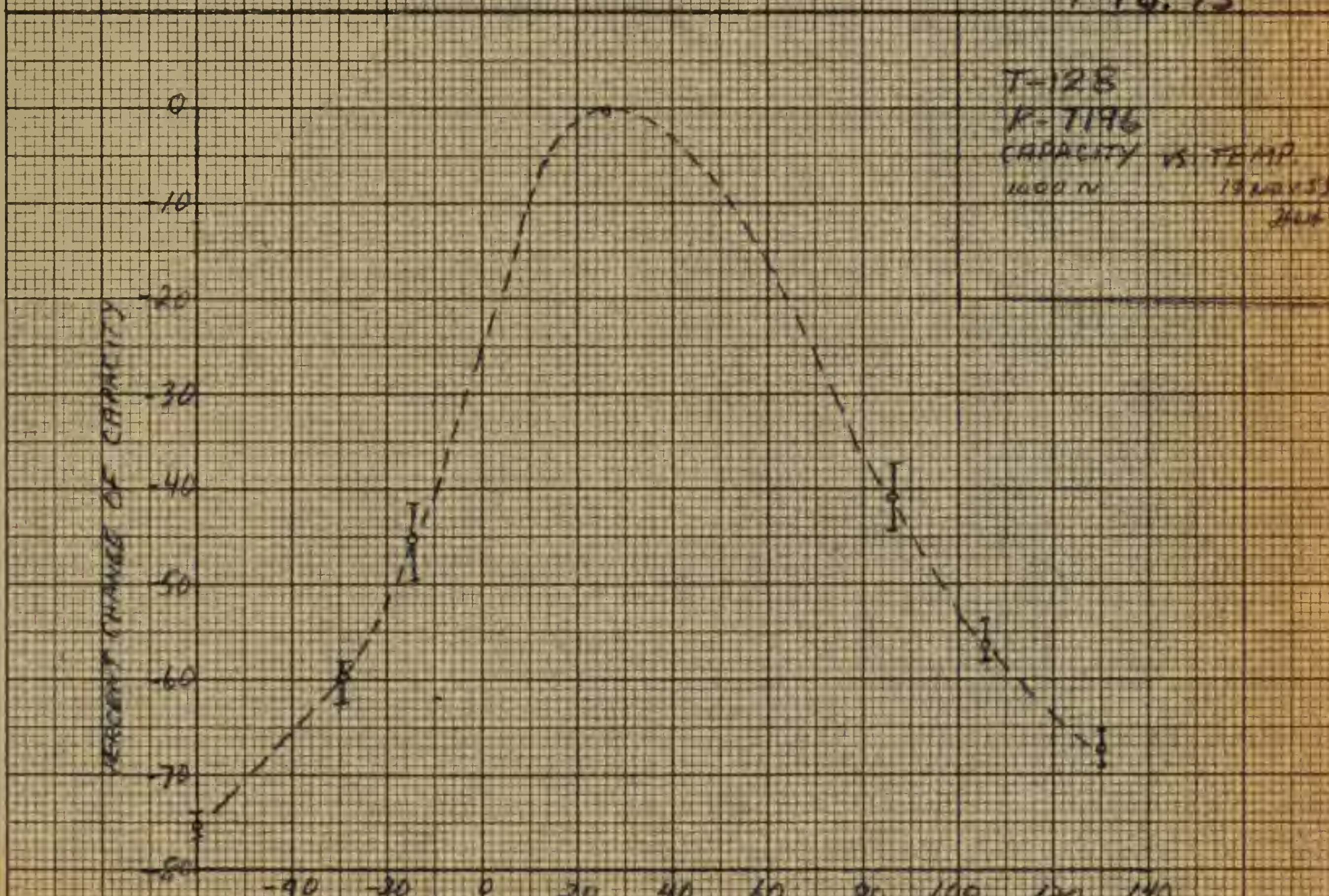

T-128
K-7196
CAPACITY VS. TEMP.
1000 ~
19 NOV 53
PERCENT CHANGE OF CAPACITY
TEMPERATURE - °C
0
-10
-20
-30
-40
-50
-60
-70
-80
-40
-20
0
20
40
60
80
100
120
140

FIG. 16

Alsimag Body No.	Temperature Range of K Peak
T-133	Above + 85°C
T-145	No definite peak between -55 and +85°C
T-106	+10°C to +50°C
T-131	No definite peak between -55 and +85°C
T-137	No definite peak between -55 and +85°C
T-111	+20°C to +60°C
T-128	-5°C to +25°C

Decay of K

The decay in K of Class II bodies is approximately a linear function of logarithmic time. The decay characteristics for several Class II bodies are shown in Fig. 17 and is approximately 5% per decade hour.

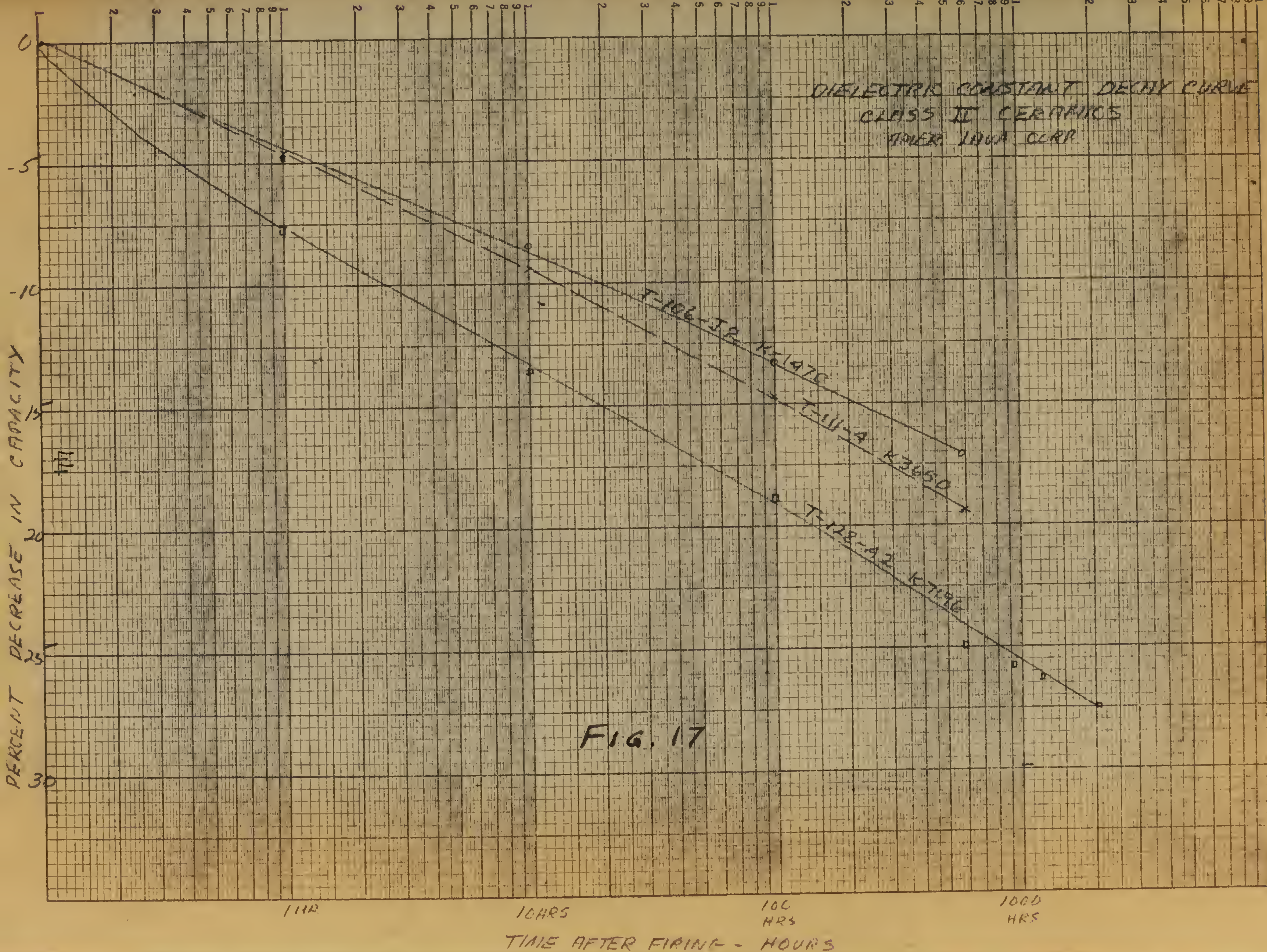
Reheating a well-aged high K body causes an immediate rise in the K of the body as shown in Fig. 18. A well-aged T-128-K7000 body, when reheated to 198°C increased its K value by 33%. The k decay curve then repeated itself. Reheating the body to 115°C caused an increase of 21% in K value and again the decay curve repeated itself.

Decay of Dissipation Factor

The decay of dissipation factor is shown in Fig. 19 plotted against logarithmic time, and it is noted that this curve levels off after about ten hours.

Insulation Resistance

The manufacturer of ceramic discs (American Lava Corporation) specifies a minimum insulation resistance of 100,000 megohms for all Class II bodies with the exception of T-111 which has a specified minimum of 20,000 megohms insulation resistance. Tests have been run on Class I and Class



DIELECTRIC CONSTANT DECAY CURVE
CLASS II CERAMICS
AEROVOX CORP
T-106-J2 K=1470
T-111-A K=3650
T-128-A2 K=7196
PERCENT DECREASE IN CAPACITY
0
-5
-10
15
20
25
30
1 HR
10 HRS
100 HRS
1000 HRS
TIME AFTER FIRING - HOURS

FIG. 17

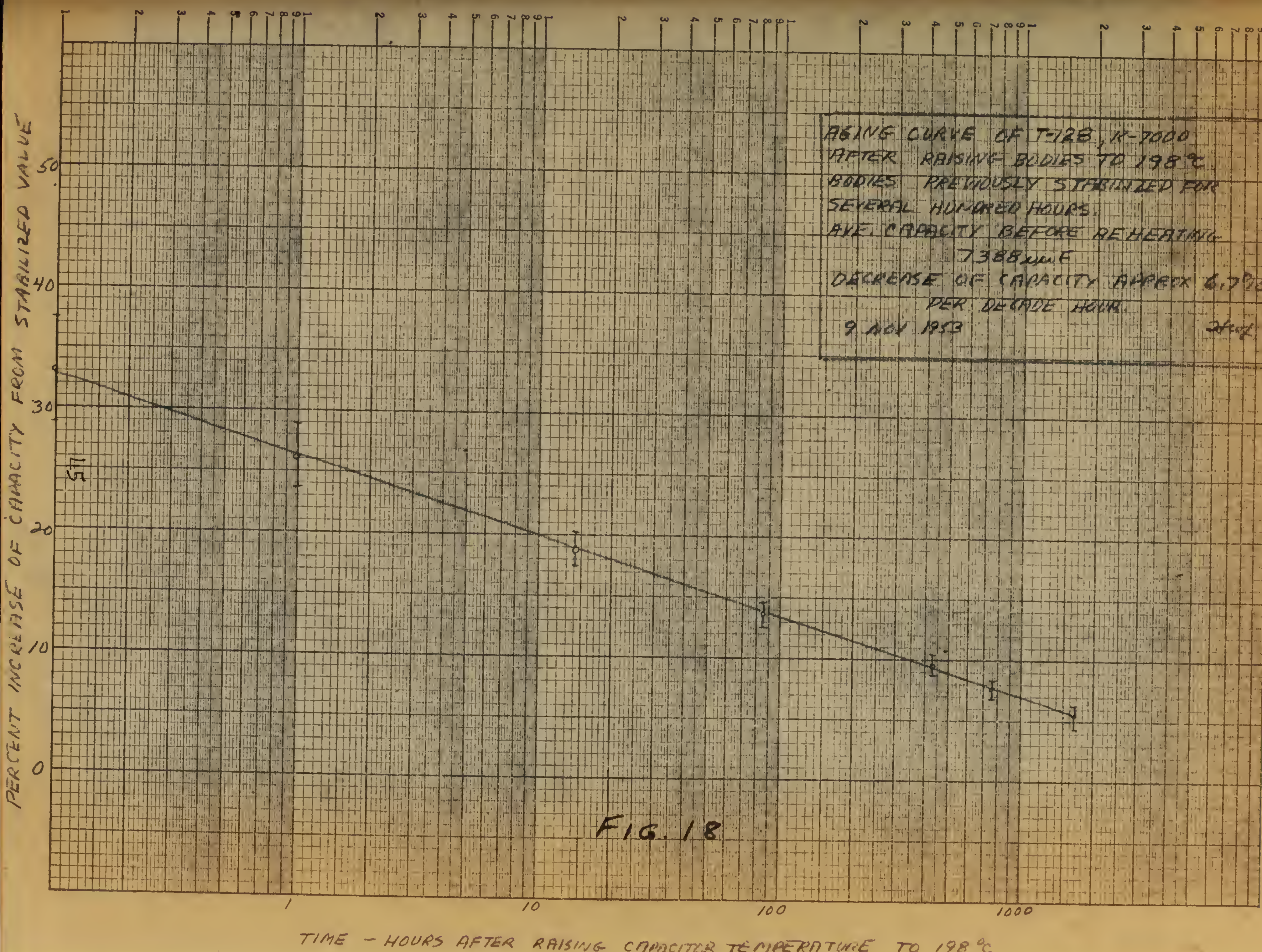
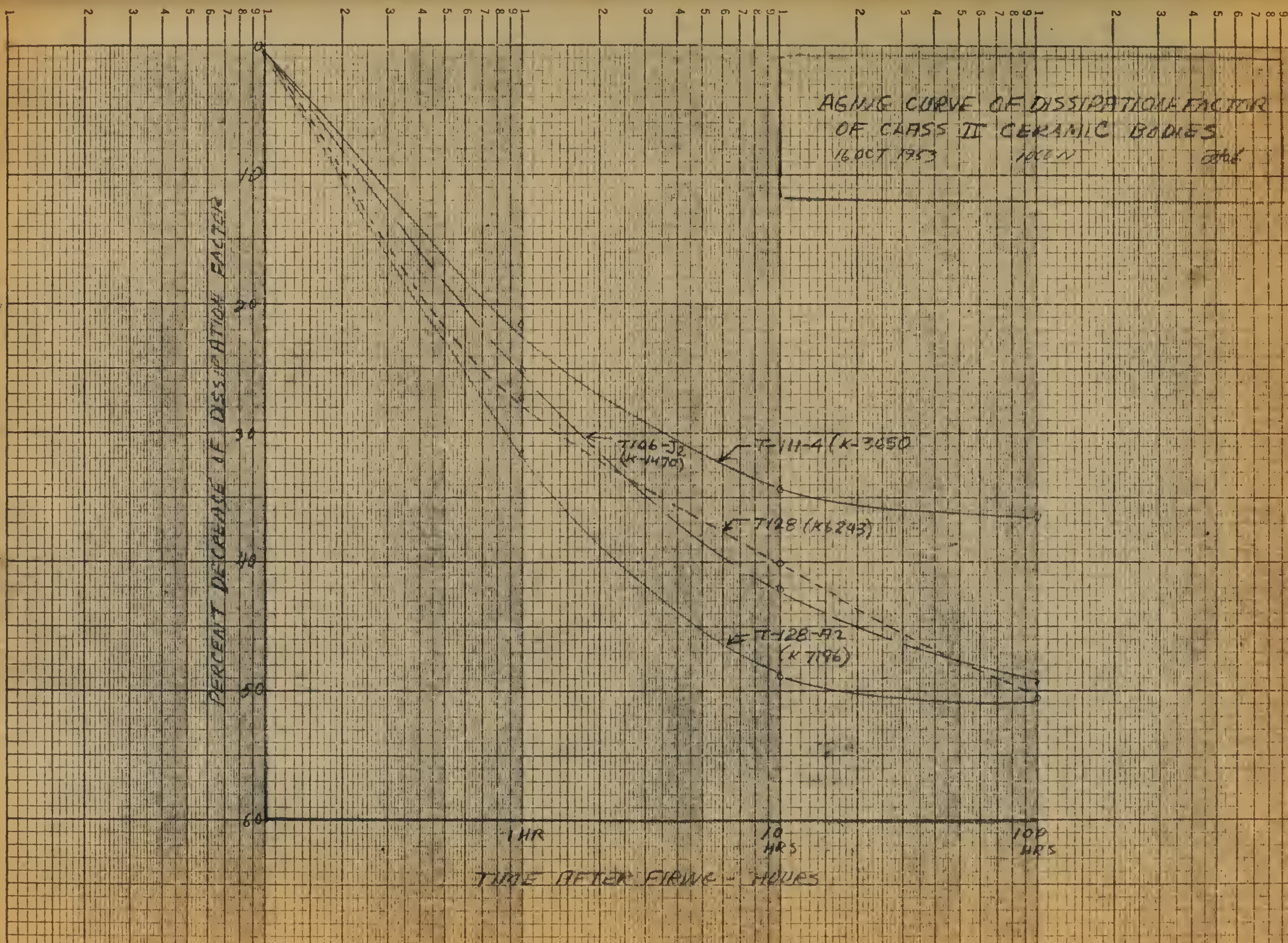

AGING CURVE OF T-128, K-7000
AFTER RAISING BODIES TO 198°C.
BODIES PREVIOUSLY STABILIZED FOR
SEVERAL HUNDRED HOURS.
AVE. CAPACITY BEFORE REHEATING
7388 μμF
DECREASE OF CAPACITY APPROX 6.7%
PER DECADE HOUR.
9 NOV 1953
PERCENT INCREASE OF CAPACITY FROM STABILIZED VALUE
0
10
20
30
40
50
1
10
100
1000
TIME - HOURS AFTER RAISING CAPACITOR TEMPERATURE TO 198°C.

FIG. 18



AGING CURVE OF DISSIPATION FACTOR
OF CLASS II CERAMIC BODIES.
16 OCT 1953
T-111-4 (K-3050
T106-J2
(K-4470)
T128 (K6243)
T-128-A2
(K 7196)
PERCENT DECREASE OF DISSIPATION FACTOR
10
20
30
40
50
60
1 HR
10 HRS
100 HRS
TIME AFTER FIRING - HOURS

FIG. 19

II bodies and all pass JAN-C-20A specifications F-15B(3)B. Where extremely humid conditions are anticipated, coatings of Hysol 6101 provide good protection and give an extra safety factor. Where humidity conditions are not so extreme, insulation resistance will remain high enough for any application.

Voltage Rating

The manufacturer of ceramic discs (American Lava Corporation) specifies a dielectric strength of 100 VDC per mil of dielectric thickness (bodies are 0.020" thick). The capacitors are conservatively rated at 300 WVDC.

3. Tape Resistors

Tape resistors used with the modular construction are of two types. The first resistors used were cured-on or "wet" tape resistors. These are made up on strips of tape and are not permanent until they are cured onto the wafer by the application of heat in an oven. This type is still being used, but has some faults not found with the pre-cured or "dry" tape resistors. The "wet" type changes value during the curing process and the amount of change must be considered when making measurements before application to the wafer. This change is not to constant (± 20%) so a large number of wafers must be discarded after curing or a part of the tape must be ground off to raise the resistance to the desired range. The resistor tapes must be stored in a refrigerated place before application to the wafer. These faults are not found in the "dry" type resistors, and therefore they are gaining in favor. The pre-cured tape is cut into strips after curing and can be controlled in resistance over a fairly wide range by varying the width of the resistor. The large bulk

tape has the resistance material sprayed on and this material is changed to make course adjustments in the final resistance desired. By adjusting the width of the resistors in the cutting process, fine adjustment in the resistance is made. Because the tape has already been cured, there is no further change in resistance to be considered. After the resistors are cut they can be stored like conventional resistors. A late method is to leave the resistors of one value in a long strip which can be rolled up for easy storage, and when a resistor is needed, it can be cut off the end of the roll. The adhesive has previously been screened on, so the resistor can be speedily affixed to the wafer by the use of a hot iron with a special tip. This application process is shown in Fig. 20.

Although silicone based tapes are relatively unaffected by water, they are affected by the organic solvents that are used for disolving flux residue. These solvents, which are used in the dip soldering process, tend to increase the resistance of the tape resistors. Protective covers of teflon or mylar have proved satisfactory for preventing this change of resistance and also protect the resistor against moisture. Clear mylar was tried for this covering, but it tended to hold the heat in and decreased the rating of the resistor. Black teflon radiates some of the heat and decreased the temperature of a fully loaded resistor by about 10°C over the unprotected resistor.

Power Dissipation

The tape resistor is capable of dissipating 1/4 watt up to an ambient temperature of 150°C. These resistors pass the JAN-R-11 specifications for maximum load life. The heat generated by a 1/4 watt load on the resistor is not proportioned evenly over the tape length but is concentrated near the center.

Fig. 20

SANDERS ASSOCIATES INCORPORATED

Temperature Coefficient

The temperature coefficients for Allen-Bradley resistors are given in Fig. 21 and for the pre-cured tape resistors in Fig. 22. These graphs show percent change in resistance as a function of resistance value for three temperature conditions. The curves are drawn by connecting the maximum points of resistance change for a large number of resistors. Many of the resistors had a change considerably below the maximum shown. The curves are based on unloaded resistance values.

Voltage Coefficient

Most of the tape resistors tested changed less than 2% in resistance value from full rated continuous working voltage to 0.1 rated continuous working voltage. Those that did change more than 2% had voltage coefficients of .02% per volt or less. Allen-Bradley resistors change less than 1% over the same voltage range. A maximum change of .035% per volt is specified in JAN-R-11.

Temperature Cycle

All tape resistors have passed JAN-R-11 specifications for the temperature cycle test (F-12) which allows no greater than 3% average change, nor greater than 5% maximum change after cycling. Allen-Bradley 1/2 watt resistors are less susceptible to temperature cycling change by a factor of approximately 3 to 1.

Noise Figure

JAN-R-11, amendment 5, eliminates noise measurements for resistors. Tape resistors under one megohm in value pass the JAN-R-11 noise test as it was presented before amendment. The pre-cured tape resistors are inferior to the cured-on tape resistors insofar as generated noise is concerned and both types are inferior to the low noise generated by the

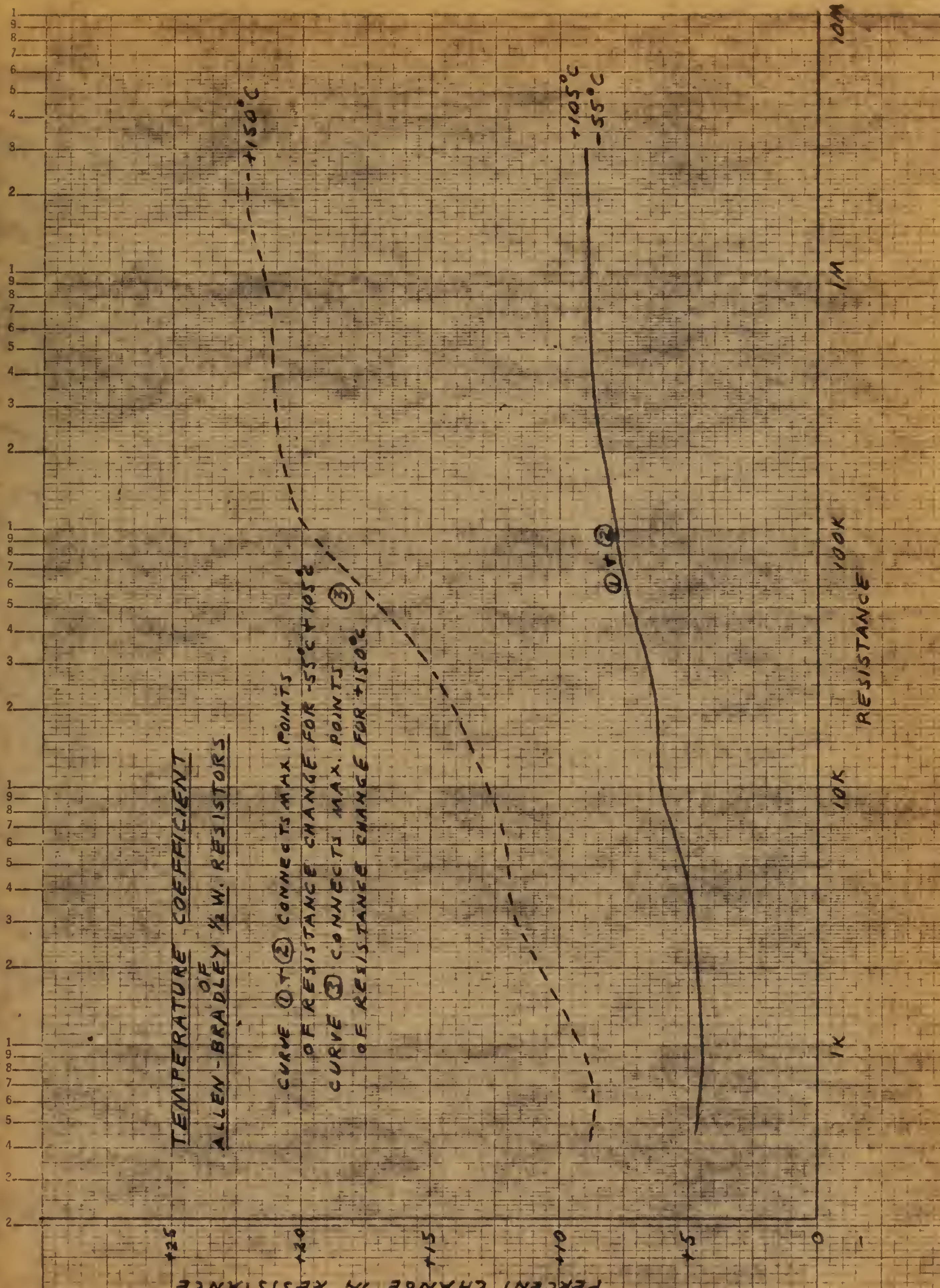

TEMPERATURE COEFFICIENT
OF
ALLEN-BRADLEY ½ W. RESISTORS
CURVE ① + ② CONNECTS MAX. POINTS
OF RESISTANCE CHANGE FOR -55°C + 105°C
CURVE ③ CONNECTS MAX. POINTS
OF RESISTANCE CHANGE FOR +150°C
+150°C
+105°C
-55°C
① + ②
③
PERCENT CHANGE IN RESISTANCE
+25
+20
+15
+10
+5
0
RESISTANCE
1K
10K
100K
1M
10M

FIG. 21

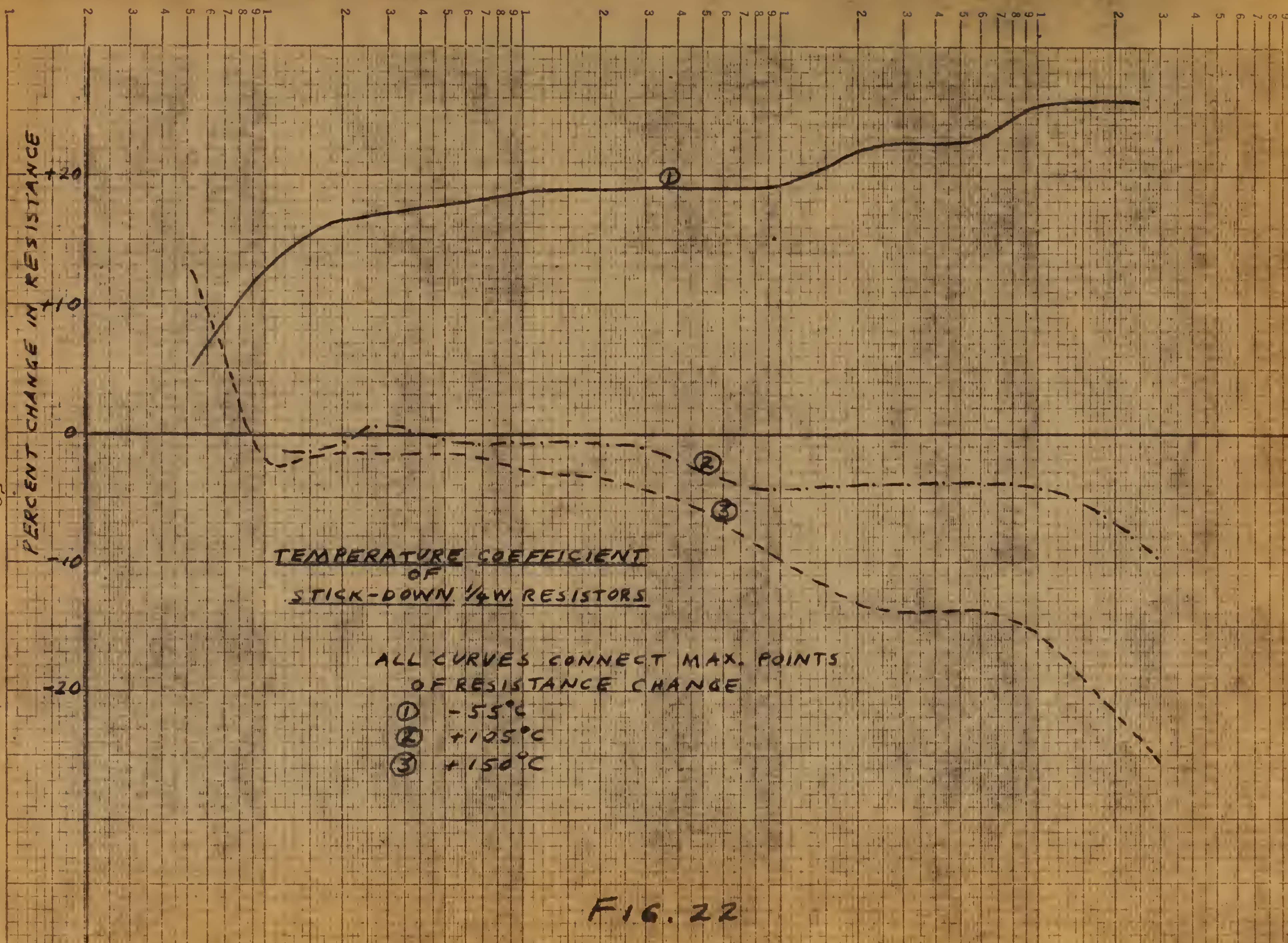

5th lines accented
MADE IN U. S. A
PERCENT CHANGE IN RESISTANCE
+20
+10
0
-10
-20
TEMPERATURE COEFFICIENT
OF
STICK-DOWN 1/4W. RESISTORS
ALL CURVES CONNECT MAX. POINTS
OF RESISTANCE CHANGE
① -55°C
② +105°C
③ +150°C

FIG. 22

Allen-Bradley 1/2 watt resistors.

Humidity

JAN-R-11 (F-14) specifications state that resistance change shall not exceed 10% with humidity. The resistance of pre-cured protected tape resistors do not change greater than 3%. Unprotected resistors change about 9%. Allen Bradley resistors change about 3%.

Short-time Overload

The resistance of pre-cured protected resistors does not change greater than 5% in value after a five second application of 2.5 times rated continuous working voltage. This passes JAN-R-11 (F-16) specifications. Allen-Bradley 1/2 watt resistors are far superior to tape resistors in this test.

High Altitude Flashover

Pre-cured tape resistors do not flashover with a five-second application of twice rated continuous working voltage at 3.4 inches of mercury. This pass the JAN-R-11 (F-7) specifications.

4. Mechanical Strength of Modules

Modular construction is able to withstand severe vibration, acceleration, and other environmental conditions. Tests have shown that when modules are properly soldered to the baseplates, damage resulting from vibration of a module with a tube mounted on it occurs in the following order:

1. Tube elements become loose
2. Tube elements break away
3. Tube pins break at the glass seal
4. Modular Tube socket recepticles break at the 90 degree bend.

5. Riser wires fracture between baseplate and bottom wafer or between two wafers near the baseplate.

6. Module breaks away from baseplate with some riser wires pulling out of baseplate and others fractured near bottom wafer but intact on the baseplate.

These tests were made using one baseplate. The structure becomes stronger when two baseplates are used. Modules with no tubes mounted on them have shown no signs of fatigue in any of the vibration tests. This rigidity may be attributed to the fact that the modules are lighter than normally used components, and have many points of support.

It is noted that the riser wires usually break near the baseplate (this would be expected), so the modules should be designed so that riser wires are not cut between the wafers next to the baseplate if it is possible to cut them in some other place. Modules should be designed so that they have a minimum of four and preferably six risers to support them. The supporting risers should be spread so that at least one riser is used on each side of the module. The use of two baseplates increases the strength considerably, but even with the two plates, the above rules should be followed if convenient.

Much better solder joints on the modules have been achieved by the use of dip soldering methods than with the use of soldering irons. An automatic dip soldering tank for use with experimental work or limited production is shown in Fig. 23. The wafers are placed in the jig shown on the front of the machine and are clamped into place while the first side of the module is being dipped. Three riser wires are placed on the

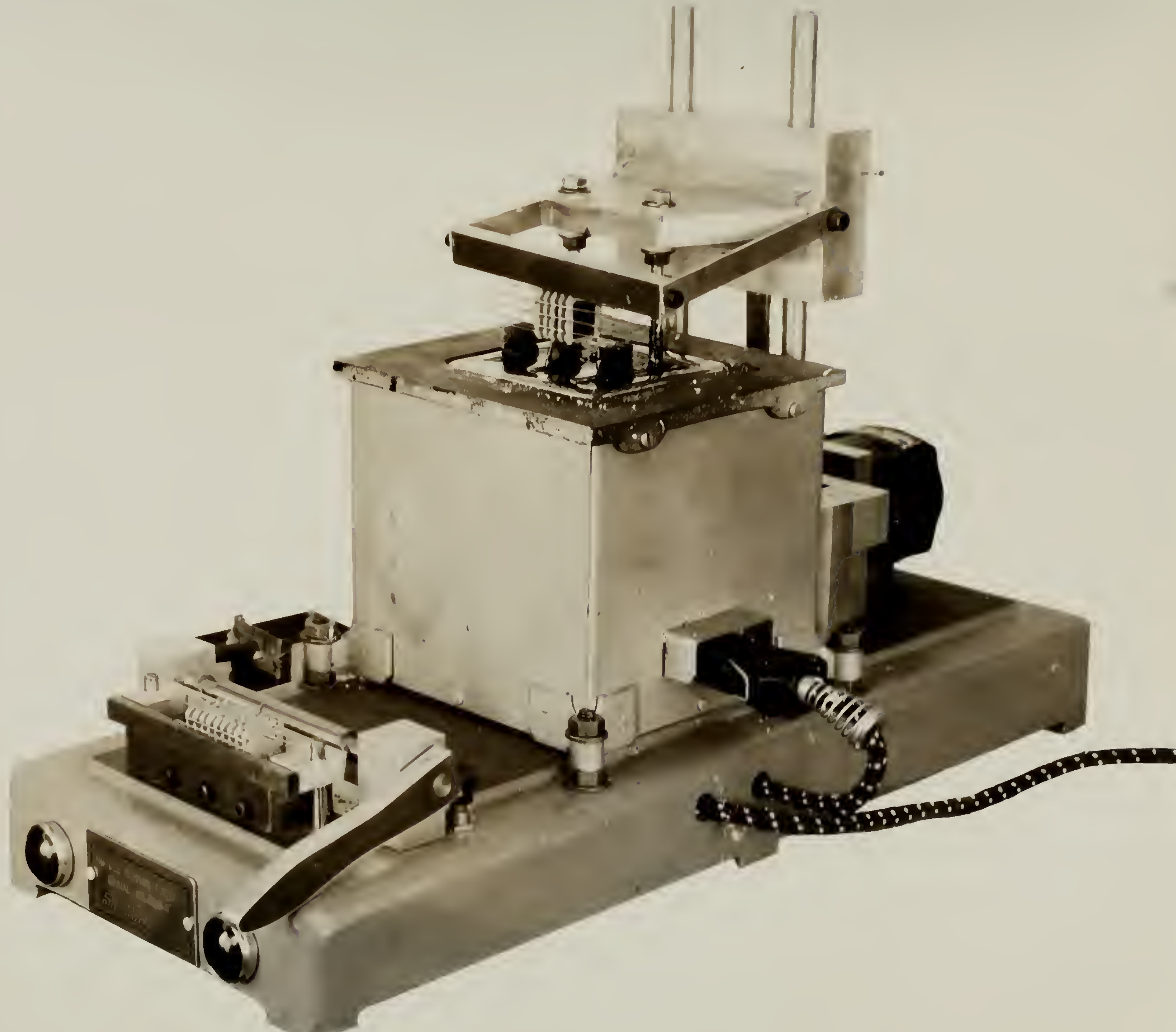


Fig. 23

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supports rising out of the solder and the wafers in the jig are placed on the wires. The machine automatically cycles and one side of the module is complete. The jig is removed and the other sides are soldered in the same manner. This process has worked exceptionally well, producing perfect joints. The problems of solder supply, and correct iron temperature and position which give trouble with the automatic irons have been effectively eliminated.

CHAPTER IV

CONCLUSIONS

Many problems have been pointed out but few of the advantages of modular construction have been mentioned. The advantages have been covered rather thoroughly in previous papers and many of them are obvious. It has not been the intention of this paper to imply that the design of modularized equipment is difficult. The design actually differs little from that of conventional circuits and the layout problems are usually easy to solve after the engineer has had a little experience.

One basic difference occurs with this design. With conventional equipment, the circuit is built in a "breadboard" fashion and made to operate, and then the components are rearranged to comply with the space requirements of the final unit. With modular construction a "breadboard" layout is also constructed, but large changes in operation may take place when the circuit is made in the modular form. Therefore a large part of the experimental work must be done in a somewhat final form. With good planning, the stray capacities are usually less in the modular form. One feature of this construction is the fact that the stray capacities are very reproducable. After the modules are designed the leads cannot be moved around, so this requires that the overall physical layout of the final equipment be made before the circuit layout can be made. Since the circuit must be laid out before it can be thoroughly tested, the overall physical layout of the equipment with control locations, etc., must be one of the first steps in the design.

This construction is particularly adaptable to miniaturization because of the ease with which the small components can be assembled. Many

miniaturized circuits are so compact that repair is almost impossible and construction time is prohibitive. The sample problem given demonstrates the value of modular construction very nicely. To build this circuit in the same space using standard techniques would be practically impossible.

One of the limitations at this time is the low value of dissipation allowable with the tape resistors. They may be paralleled, but this is not a very good way to have to build equipment. Work to increase the dissipation has been done, but no solution has been found yet.

No mention of inductors was made because no significant advancements have been made in this field since Ref. 1 and Ref. 2 in the bibliography were written.

More stable condensers of the ceramic type are needed even though those available are no worse than the conventional disc ceramic condensers.

It can be seen that much work is still required in the components field for modular construction, for the equipment is no better than its individual components. In spite of the limitations that still exist it must be admitted that the progress has been rapid considering the short time that has elapsed since the idea was conceived.

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Stamps

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